THE EFFECT OF VOLUNTARY ACTIVITY ON THE KNEE-JERK

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I. INTRODUCTION

The knee-jerk is at present considered to be a reflex. The history of this question has been presented by Fulton (16), and Fearing (15). The nature of the knee-jerk is fully presented by Wendt (61). The point of action of the stimulus has been shown by Fulton and Pi-Suñer (17) to be sensory fibers within the muscle. It consists of the shortening of an extensor muscle, *quadriceps femoris*, in response to a sudden stretch of the muscle. With all tendon-jerks, it is termed the 'phasic reaction' of the stretch reflex. The other type of stretch reflex, the 'static reaction,' is a response of largely the same neuromuscular

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mechanism to a slow stretch. Since the blow upon the tendon, serving as the knee-jerk stimulus, is a sudden, quick and brief stretch of the tendon and muscle, practically all the muscle fibers respond simultaneously, except those in refractory phase due to the normal tonic contraction. The lower leg is thus caused to kick forward. This twitch is followed by a secondary contraction, which is a reaction of the deeper lying and slower acting elements of the muscle (7). It is considered to be a "fractional manifestation of the stretch reflex" because of its dependence on tonus (48) and from other evidence (8).

The knee-jerk as described is an unlearned response, judging from the fact that the mechanism reacts with apparently perfect integration upon the first application of the stimulus. The parts of this mechanism have, however, acted previously to the first tendon blow, and presumably *in utero.* The question remains open, therefore, as to whether learning has occurred before the knee-jerk is elicited at birth. It is possible to study any learning which might occur after birth. Tests have not been made from birth onwards to determine whether changes occur, particularly as related to practice in sitting, crawling, standing and walking. Such changes would be influenced, however, by physical development, as for instance the increase in length of the nervous arc necessarily involved.

Another possibility was tried in the present experiment, consisting of the attempt to alter the knee-jerk of the adult through a learning process. There are a number of facts about the knee-jerk which make it plausible to hypothesize that it will be altered by learning, according to Dunlap's view (12). Firstly, it varies in latency or reaction time, degree or height of contraction, and in shape of contraction curve (15). Secondly, the occurrence of other reflex activities is influenced by it, at least in the case of contralateral flexion (45). Thirdly, its variations depend on other concurrent activities of the individual, particularly those requiring cerebral action. It has been shown by Pfaffman and Schlosberg that there is a positive relation between the facilitatory effect of a bell and the ease of conditioning the knee-jerk to it (39). (The conditioning of the jerk is an alteration of the response by chang-

ing the stimulus end of it, which is a different kind of alteration from that mentioned above, in which the action is affected.) Whether attention on the knee-jerk facilitates or inhibits it does not appear to be settled. This question is brought up by Fearing (14, 15). It was early suggested by work of Klarfeld (31) that the cerebrum has an inhibiting effect upon the knee-jerk, and this has since been corroborated by other physiologists. Further details will be found below in section III, the historical survey.

II. THE PROBLEM

On the basis of the preceding discussion, the hypothesis is advanced, that repeated concurrent voluntary leg activity, whether it inhibit or facilitate the knee-jerk, will have some effect on the action phase of the response, due to learning. The problem of the present investigation was to determine whether a leg response practiced to a knee-jerk stimulus or its tactual component can become involuntary, and whether the reaction time of such a response may approach with practice that of the knee-jerk; and further, what effect the practice may have on the knee-jerk time.

The specific details of the problem were to determine: whether the knee-jerk can be reversed by practice of a back kick to a knee-jerk stimulus, or whether a kick of the opposite leg can be substituted for it; what may be the time relations of kicks of various types, such as knee-jerks, knee-jerks accompanying the voluntary kicks practiced, the voluntary kicks themselves, and voluntary kicks in response to a touch on the knee or elsewhere; and whether the knee-jerk can be produced, that is, the threshold lowered, by voluntary practice.

The questions arise, whether learning will occur when the subject is not consciously trying to accomplish the response to be learned, when there are no errors to be eliminated, and when there is not definite motivation. The change in the reaction time of the knee-jerk with change in the strength of the blow is also studied.

The method may be said to be that of conditioning provided it is assumed that the voluntary response, if it inhibits the knee-

jerk, will eventually replace it as a response to the tendon blow. The conditioning in this case would not be of the knee-jerk, but of the voluntary response. S_1 is whatever sets off R_1, the voluntary response, and may be instructions and intentions, the blow serving merely as a minor part of S_1. S_2 is the blow eliciting the knee-jerk R_2. After repetition of S_1 and S_2 together, S_2 may elicit R_1.

III. HISTORICAL SURVEY

A. Introduction

The experiments of a number of authors tend to demonstrate that voluntary control of reflexes can be gained. Karger has presented data showing that it is possible voluntarily to increase the knee-jerk. This was accomplished by a voluntary contraction of *quadriceps* without allowing the leg to move, begun before the blow (29). This effect seems to be the same as that found earlier by Dodge (9). Peak found that voluntary sets, toward a wink or a finger movement to be made in response to a stimulus to the reflex wink or finger movement, increased the respective reflexes stimulated during the set. The voluntary movement followed the reflex, but anticipations also occurred, since the time interval between the signal for the set and the stimulus to the reflex was constant. The latency of responses recognizable as reflexes was greater with sets than with relaxation, although her results were admittedly confusing (37). Hudgins successfully caused the pupillary reflex to come under voluntary control without the subject's intention or knowledge. He conditioned the reflex to a bell, then the bell itself was rung by the subject by a hand response at the command of the experimenter. Finally the hand response and bell were eliminated, and reinforcements proceeded, the conditioned stimulus being the command. Conditioning was successful even when the subject himself gave the command at the proper signal (26). Steckle and Renshaw did not obtain clear or regular conditioning with a similar procedure, and found that adaptation of the pupillary reflex occurred (50). Gibson and Hudson conditioned the knee-jerk to a facili-

tating voluntary hand reaction with attention on the reaction, which, however, preceded the knee-jerk. They found transfer of the conditioned response to the other leg to be easy (18). It seems reasonable that voluntary control of the knee-jerk could be obtained in the manner of Hudgins' experiment.

The present experiment does not bear on voluntary control of the knee-jerk, but on the influence of voluntary activity upon it, and in particular on any influence which outlasts the series when a voluntary response was practiced. A similar procedure was employed by Wendt in series taken in order to compare voluntary leg reactions to a blow on the opposite tendon with knee-jerks conditioned to a blow on the opposite tendon (61). He also obtained them to other stimuli. Fourteen of his subjects were engaged in reading while making these voluntary reactions, and two were not. For five of these subjects these series preceded the conditioning series. Most of the subjects reported that the voluntary kicks to a tendon blow became automatic, although in varying degree, and seemed easier to perform than those in response to other stimuli. With a ready-signal they ranged in reaction time from 100 to 180 sigma, and without the ready-signal, from 120 to 200 sigma. Those to a sound cessation were 40 sigma slower, and those to a touch on the tibia, on one subject, were between the other two types. In 9 out of 12 subjects automatic bilateral responses which appeared after conditioning were increased in frequency after voluntary practice.

There was evidence in some subjects of a decrease in the knee-jerks accompanied by the voluntary kicks. This finding is corroborated by the present work.

Wendt succeeded in altering the reflex pattern by conditioning the knee-jerk to a blow on the opposite knee. The final pattern of response to that blow not only often included a conditioned contraction of voluntary reaction time, but a shorter-latency bilateral contraction of which the latency was similar to that of the secondary contraction of the usual knee-jerk curve. The blow to the other leg preceded the unconditioned stimulus by $\frac{1}{5}$ second. The reaction times were measured from kymographic muscle thickening curves, with a 50 d.v. time line. The reaction

time of the first response was variable, the medians for the subjects ranging from 128 to 335 sigma, and it occurred generally to either of the two blows. It was more easily formed in subjects where there was a strong facilitation of the second response by the first blow, and was fairly persistent in some cases. It appeared in 10 of 12 subjects.

Cason found that the reaction time of voluntary winks as measured by the Bergstrom chronoscope was decreased by the conditioning process. He used 500 to 3000 reinforcements of a sound and electric shock, the sound being the conditioned stimulus (4).

Wendt quotes from a report of Dodge (11) concerning experiments containing elements similar to his own, as follows:

> An effort was made to produce crossed reflexes by simultaneously stimulating the two knee-jerks. "In spite of hundreds of cases of simultaneous stimulations true crossed reflexes were never elicited. Similarly, simultaneous stimulation of the right and left final common paths to the quadriceps by voluntary effort and by normal reflex stimulation, respectively, also failed to produce a reconfiguration of the mechanism of the knee-jerk". Pp. 68–69. In another experimental series two knee-jerks were elicited from the same leg at an interval of $\frac{1}{2}$ second. In spite of hundreds of repetitions the second stimulus was never anticipated (61, p. 34).

The relation of higher nervous centers to the knee-jerk should indicate how much of an influence could be expected from voluntary action. Golla and Hettwer say that activity of the cerebral cortex is the greatest factor in the variation of the human knee-jerk (19). Walton and Paul make note of a fact often neglected: that the brain can increase as well as inhibit "reflexes." Higher nervous arcs usually, however, produce more subdued and deliberate "reflexes" than lower arcs (58). Reflexes of this type may be represented by the 'tonic' or 'static' secondary contraction of the knee-jerk, which, however, according to Wendt, are probably mediated by or facilitated through the action of nervous centers higher than the lumbar segments of the spinal cord (61).

The absence of the knee-jerk during sleep has often been reported, although the criterion of sleep is doubtful (27, 32). This absence appears to be an effect of the cerebrum through relaxation. The relation between relaxation and tendon "reflexes" is demonstrated by Hoffmann (23), who concludes that tendon "reflex excitability depends directly upon the state of contraction of the muscle." He finds that decrease of the Achilles jerk, caused by voluntary contraction of the antagonists, is due to a relaxation in the muscle. Dodge, on the other hand, finds that voluntary depression of the knee-jerk is not accomplished through any decrease of tonus (9). The question of relaxation appears to be settled in the reports quoted in section C below.

B. The crossed knee-jerk

Some light may be thrown upon the effect of a voluntary forward kick of the opposite leg by a consideration of the sympathy or antagonism of the knee-jerk of the opposite leg. A positive functional relation between the jerks in the two legs is demonstrated in pathological cases where a 'crossed knee-jerk' has been found. This term sometimes is used to include also the more common adduction of the opposite leg. De Watteville (59) found crossed jerks with the muscular latency the same as for the percussed leg. His cases were probably abnormal. Schwartz (44) reports that in cases of cortical epilepsy and of cerebral hemiplegia with increase of tendon reflexes, often the knee-jerk springs from one side to the other when either tendon is percussed. Gotch found crossed extension without the ipsilateral jerk in man, under abnormal conditions (20). He recorded them by means of tambours. He found the latency to be longer than that of the leg stimulated: 110 to 120 sigma as compared to 80 to 90, and the muscle response was less synchronous. Souques and Chauvet (49) found in a hemiplegic whose right knee-jerk was exaggerated, a strong right extension in response to percussion of the left leg, occurring a little later than the left knee-jerk. They state that such results, including crossed adduction, have been noted by Thuë, Féré, P. Marie and Ganault. Wiersma states that the

knee-jerk spreads synchronously to the other knee with pyramidal lesions, the percussed knee being inhibited (62). Austregesilo quotes Benedikt as finding crossed extension (61). Wendt (61, p. 10) gives a list of references to crossed reflexes.

There has been some discussion of the mechanism of crossed jerks. Sternberg opposed the idea of bone transmission, in other words direct contralateral stimulation, as the cause for true crossed knee-jerks (51). Gotch found that the latencies of crossed knee-jerks in the rabbit indicated their reflex nature (20). Russell shows that higher centers are not necessary for the occurrence of crossed knee-extension in dogs and rabbits (42). It could be elicited in dogs after section of the corpus callosum when reflex excitability had been increased by induced asphyxia. It still occurred after a transverse section of the spinal cord in the mid-dorsal region. It was then elicitable even to a blow on the tibia, but without any ipsilateral jerk.

Crossed knee-jerks were found by Tuttle in a normal, hyperirritable subject. In this case the knee-jerks were high and easily affected by the environment. A simultaneous kick of the left leg to a blow on the right was obtained 144 times while the subject was engaged in conversation. There was a correlation of .97 between the heights of kick in the two legs, showing that whatever affected the right also affected the left (55). Wendt found that one of his subjects had, before conditioning, a bilateral response following the knee-jerk at a brief interval. This was similar to the response which appeared in other series after conditioning.

The possibility of a normal close relation between the jerks in the two knees is opposed by Sherrington's results. In his extensive work on animal preparations he found a relation between flexion in one leg and extension in the other. He found, however, that in a decerebrate cat the isolated vastocrurei could be made to contract and relax together with equal stimulation of both afferent nerves, provided the conditions of the muscles were similar (47). Minkowski found crossed extension occurring with flexion in the human foetus (34). This has also been observed in spastic paralysis (55). Wendt suggests that the integration

between the receptors to stretch in one extensor, and the contralateral extensor, may be on a higher level than that between them and the ipsilateral extensor (61). Supposing the integration with the contralateral flexor to be at the lowest reflex level, the two opposed tendencies in the opposite leg would slightly succeed one another.

Mitchell and Lewis state that tapping the tendon of the opposite leg does not increase the knee-jerk (35). Cornil and Goldenfoun, however, used such a blow as facilitation in conditioning the knee-jerk (61, p. 33). Wendt found that the effect depended on the time relations but that facilitation occurred if the facilitating blow preceded the knee-jerk stimulus by 100 to 300 sigma. With simultaneous blows and at a 500-sigma interval the excitability was lessened. He suggests that facilitation at the longer intervals "involves discharge from higher centers than that at short intervals" (61). A special functional connection between the knee-jerks is not considered, however, necessary to facilitation. In regard to the records he made of voluntary kicks, it may be remarked that if there were no functional connection between the two knee-jerks we should expect the reactions to sound to be the quickest instead of the slowest, or at least that there should not be such a great difference.

C. Certain factors affecting the knee-jerk

The knee-jerk in the present study is viewed as a neuromuscular response following the evidence presented by Hoffmann (25) and others previously mentioned. It may be used in walking; at least walking can include a physiological extension reflex (46, 3) employing the same neuromuscular units as the knee-jerk.

The latency of the knee-jerk was found by Wendt to be 30 to 50 sigma. He used pendulum hammers, electric stimulus marking and a lever and pulley system recording muscular movement on a kymograph. For 18 normal subjects Castex found the minimum muscle thickening latency to range from 29 to 40 sigma (6). Fearing (15) gives the earlier results. Muscle thickening records taken with a tambour containing water are 10 to 50 sigma less than those taken from foot movement (60). The action current

latency was found by Nystrom to be 19.4 sigma, and muscle thickening latency taken at the same time to 32.0 sigma on the average for 29 subjects, with a correlation of .783 between them (36).

"Psychical and physical effort" increasing the knee-jerk were found by Golla and Hettwer to decrease the latency measured with the string galvanometer (19). Certain other factors affecting the knee-jerk have special bearing on the present investigation. Wendt gives a summary of a number of facilitating and depressant factors (61, p. 18).

The frequency with which blows are given may affect the reaction time. The refractory phase, according to Dodge, is conspicuously less than that of the eyelid reflex (9). Lee and Kleitman say the extent is influenced by a blow less than 15 seconds previous to the eliciting blow (32). Strughold found the absolute plus relative refractory period for six subjects to be 4 to 5.7 seconds. He used a spring hammer and registration by a string galvanometer, as well as from an air-filled rubber cuff about the muscle. He also found that facilitation affects the refractory phase. It was reduced, on one subject, when a weight acting across a pulley was used to draw his leg back, so that effort was required to keep the leg vertical. The reduction was greater for a heavier weight, and the effects were reversed, when a weight was attached so as to pull the leg forward. The Jendrássik handclasp, and facilitation by raising weights with the hand or other foot, decreased the refractory phase. Strughold measured the refractory period as the first interval between successive blows at which the second jerk was increased above normal (52). This does not mean that the effect of a jerk cannot last more than six seconds. Wendt found that a half-minute interval was sufficient to avoid facilitation effects of one response on the next.

Mechanical reaction time is found to be less with greater intensity of blow in exaggerated knee-jerks, tonus being constant (5), and in normal knee-jerks. Rosenheim found this effect, using a pendulum hammer which made a circuit, and a device on the muscle which broke it, through a marker (41). Weiler used

a water-filled tambour (60). Wiersma used 3 blow speeds on 3 subjects with tambour muscle recording (62). Golla and Hettwer found the latency of the action current to decrease with increase in energy of blow. They used progressively weighted pendula, the velocity thus being practically constant (19). This differs from Dodge's finding with the mechanical latency that velocity and not mass produces the effect (9). E. Castex increased regularly the energy of the blow, probably by increasing the velocity, and found that the energy of contraction and the amplitude increased to a maximum, while the reaction time concurrently diminished to a minimum (6). It seems to be true that there is an optimum range for both speed and mass of the blow, dependent on the amount and speed of the muscle stretch which serves as the most efficient stimulus; and that within the range of either, progressive increase can decrease the latency of the response.

H. Piéron has found that the Jendrássik handclasp shortens the knee-jerk latency (40). It is a common observation that it increases the extent since the study of Lombard (33), and similarly it appears reasonable that extent and latency appear in inverse ratio. Varnum confirmed this fact with records from the movement of the foot (56).

The temporal position of a series of records in an experimental sitting usually affects their reaction times. Dodge made extensive tests on one subject in four-hour periods with six knee-jerk stimuli in each hour. The average reaction time for all the days increased during the four hours from 30 sigma in the first to 40 sigma in the fourth hour. Recording was by means of muscle thickening curves photographically registered. The extent showed no systematic changes (11). Similar effects were noted by Rosenheim, who found that the reaction time was increased as more blows were given (41), and by Travis and Young. They averaged the first and last 20 string galvanometer records for each of 5 sittings of 40 records each and found an increase of slightly over .1 sigma of the second 20 over the first 20 (54).

The cause of this decrease may be found in work on knee-jerk extent. Jacobson found the knee-jerk to disappear with supine

relaxation (27). With Carlson he found that the knee-jerk decreased parallel to the degree of relaxation (28). In 21 subjects, who were given 27 periods each of 40 to 70 minutes, the knee-jerk extent decreased on the average during a period. Blows were given with a spring hammer, usually at 30-second intervals. Nothing was said to these subjects about relaxation (27).

It was found by L. T. Brown that physical exercise may decrease the knee-jerk by causing excessive fatigue. (2). This effect was limited to non-athletes, and as subjects in the present study devoted little or no time to athletics, it may be a factor contributing to decrease of the knee-jerk. Hoffman found no effect due to normal fatigue caused by voluntary activity (23).

Adaptation due to repetition of the knee-jerk blow does not appear to occur. A report of an experiment considering this question is now in preparation. Hoffman found no adaptation of the Achilles jerk to occur when induction stimuli were applied at 45/second (24). In the study of Dodge (11) last mentioned above, 1032 stimuli were given over a period of 18 months. The reaction times showed "a clear shift of central tendency" towards greater values in frequency distributions of the last few days' records as compared to the first, and the extent was slightly diminished. Lee and Kleitman found that the knee-jerk disappeared in all tests after several months of work on one subject (32). Since it could be obtained with simple facilitation, such as conversation, its disappearance can be explained as due to practice in relaxation, without recourse to adaptation as an explanation. Relaxation also serves to explain the results of Dodge.

IV. SUBJECTS

The subjects of experimentation were 14 in number. The women are designated as follows: Cf, Df, Ef, 1f, 3f, 5f, 6f, and 7f. The men are: Am, Bm, Fm, Gm, 2m, and 4m.

All the subjects except 1f, 6f and 7f were advanced students in psychology. 7f was a graduate student in zoology, and 1f and 6f were college students. 6f was the only one who had never had a course in psychology.

V. FIRST EXPERIMENT

The first experiment was solely an attempt to alter the involuntary response to a knee-jerk stimulus by practice of a different, voluntary leg response to that stimulus.

The subject was seated, with his lower legs hanging free, on a chair cushion curved up at the lateral edges to prevent lateral movement. Shoes and hose were not removed, but the trouser of the leg percussed was rolled to above the knee. A length of flexible rubber rod of half-inch diameter was fastened across the patellar tendon, being crossed behind the knee and clamped above it, as illustrated in figure 1. This rubber was struck by a heavy pendulum hammer just past its center of swing. The practice of placing an object across the tendon, so that variations in the position of the leg will not affect the point of application of the blow appears to have been initiated by Hoffman (22). The pendulum was dropped from an angle constant for each subject and large enough to elicit a visible knee-jerk before training. It was operated by hand, and the angle from the vertical was judged by a scale beside it. For subjects Am and Df, all stimuli but the last 1700 were given with a shoemaker's hammer.

The pendulum was 60.76 cm. in length, the bob weighed 857.0 grams and its period was 1.57 seconds. For subjects Am, Df and Gm, and for Fm at first and Bm for a brief time, it was dropped from about 26°15′. The velocity at the lowest point in the swing was 93 cm. per second, calculated by the formula

$$v = \frac{2\pi l \sin \phi}{T}$$

where v = velocity, l = length of the pendulum, T = its period, and ϕ = the angle from which it was dropped. This measure of course is not accurate, since it was not a simple pendulum. For subjects Bm, Cf, Ef and Fm the angle was 22°30′ and the velocity 107 cm. per second.

The pendulum support was adjustable in all directions. It could be turned so that the direction of the blow was in line with the upper leg of the subject. Curtains were hung so that he could not see the pendulum, his knees, or the experimenter;

except in the early work with subjects Am and Df, who kept their eyes closed instead. A tilted writing board could be set up to rest books or papers on, with lighting from the proper direction.

Subjects Am, Bm and Cf practiced a back kick of the left leg in response to a blow on the left leg, and subjects Df, Ef, Fm and Gm practiced a contralateral forward kick, the left leg responding to a blow on the right. The instructions were written and presented each day, except for Am and Df. The voluntary kick was to be made immediately after the blow, as quickly as possible. With the contralateral kick, attention was to be kept on the left leg.

It is difficult to tell how much the subjects guessed concerning the experiment. The set-up was such that they must have known they were practicing the response, since no records were taken. They tried not to be too interested, Cf apparently being most successful. Am and Df knew the precise object of the practice, as well as what was being observed.

Subjects Am and Df were given training series at intervals of from one to eight days, with systematized testing only on the last three days. The other five subjects were given training usually three times a week, with certain lapses which will be indicated. A training series was given on each experimental day and consisted of 100 blows given at irregular intervals during slightly less than 15 minutes. At first the blows were given in groups of five with a ready-signal, or with a ready-signal for each blow. On later days there was a ready-signal only at the beginning of the series and after any interruption.

To test the effect of the training, at first an unexpected blow was given. On days when this was done, the subjects Bm, Cf, Ef, Fm and Gm were instructed to pay no attention to blows during "adjustment of the apparatus." They may have thought they were expected to kick voluntarily despite the absence of a signal: if in doubt, one would expect them to do so. Am and Df, however, knew that automatic kicks were allowed but not voluntary ones. They found the distinction difficult. Am observed that he could not tell how involuntary a response was when he was not attending to it. The reports as to whether a kick

was voluntary or not may be taken as honest but not necessarily conclusive. These reports were in most cases in response to questioning, and the questions were not emphasized, other questions being also asked.

All the subjects showed some responses modified from a knee-jerk to these test blows. These will not be reported in detail. To control attention and expectation of response, testing was substituted, which was carried out while the subject worked at the Number Work Test—Johns Hopkins Series, which requires continuous addition and subtraction. The subject's instructions were to work aloud and continuously, paying no attention to what the experimenter did to his legs. The subjects could not help noticing when their legs were hit, but usually succeeded in not observing them expectantly. The experimenter did not give a blow unless the subject could be heard to be working evenly. Ten, or usually five tests were taken in this way before and after each training series. Sometimes, also, an unexpected blow was given at some other time, the results in such cases being no different from those obtained during number work. The object of this method of testing was to keep the attention of the subject distracted so that automatic and reflex kicks would not be inhibited.

The visible knee-jerks occurring with the voluntary contralateral kicks or before the back kicks were counted for each training series. The instructions to attend to the left leg when the right was being percussed were intended to combat any effect of attention on the right knee-jerk in the case of the contralateral kick. The number of visible knee-jerks varied greatly in each subject and between subjects. Knee-jerks occurred before back kicks although the subject kicked back as quickly as possible. They usually became less frequent toward the end of a series; and in four of six subjects they decreased generally toward the end of training. The exceptions were Fm and Gm, who received the least practice and who showed no consistent changes.

The responses to test blows included large numbers of knee-jerks such as appeared before any training was begun. If

they were small, they were noted as modifications of the response. Other modifications of the knee-jerk response were of these types: a kick like the one practiced (a back kick or a contralateral kick), such a kick preceded by a knee-jerk, or the absence of any visible response. Reaction times and extents were not measured, only visible leg motion being recorded. Judgment of a knee-jerk as "small" was beyond doubt subjective.

The records included in table I are those taken on days when the number work test was used as a distraction. They were all taken during the winter. For Am and Df they include also series without distraction, and the blow speeds were varied.

TABLE I

SUBJECT	TOTAL PRACTICE BLOWS	EXPERIMENTAL DAY TESTS BEGUN	TOTAL TEST BLOWS	NUMBER APPEARING IN TESTS OF:			
				BK	KJ and BK	No response	Small KJ
Am	3100	29	151	1	16	23	14
Bm	2800	7	258	2	1	2	1
Cf	3100	6	313	3	15	6	7
				LFK	RKJ and LFK	No response	Small KJ
Df	3100	29	129	10	51	9	
Ef	2900	7	270	1	25	39	101
Fm	900	6	71	0	8	0	0
Gm	1700	1	185	0	3	42	59

The abbreviations used in the tables are as follows: BK for back kick, KJ for knee-jerk, and FK for forward kick.

No extended testing previous to all practice was considered necessary for comparison with the tests reported here. The back and contralateral kicks reported were certainly due to the practice. The percentage of modified responses of each type for each subject was greater in all tests following the training series with 7 exceptions, none of which fell in the BK or LFK category.

The results from Fm are questioned, as he gave the experimenter the impression that he might not be following instructions. The best results in terms of modifications of the response are evident with Am and Df, and these were obtained in test series

more extended than for other subjects, in which a relatively greater disappearance of modifications would ordinarily be expected. These tests were not made until late in the experiment, although modified responses appeared earlier in other tests. The more frequent testing of the other subjects may have had effects opposed to those of the training.

For subject Am, modified responses to test blows appeared from day 6 on, and were usually knee-jerks followed by back kicks. Eight times during the experiment he reported that back kicks made to test blows were involuntary. On a different occasion he was intentionally expecting a knee-jerk to follow a blow, but a back kick was elicited. Several test blows while he was 'relaxed' and more or less expecting knee-jerks, elicited knee-jerks and a few small back kicks. He noted that the back kicks became automatic; certain ones, more than 18 in number, he remarked as definitely involuntary. Of these, one was the first response of a series, when he was confused and kicked forward after it. Once there was an involuntary back kick of both legs. Another time he forgot what he was to do, but the kicks occurred as usual.

He tried, further, definite distractions of attention during practice. He first observed that the kicks seemed more violent when he was attending to something else. Several days later he observed that when his attention was not on his legs the kicks were not so forceful, although they occurred regularly. Once, however, he failed to kick at all when he was not attending, but at other times this was not the case. Twice when he put his attention on his right leg it also kicked back. When he performed a hand movement in response to the blow, on the twenty-eighth day of practice, he was unaware of the back kicks, although they did not fail to occur. On the thirtieth day he reported that he was not conscious of the back kicks. On the fourth day the left leg began to feel different from the right. This difference later became definitely noticeable to him when walking. Near the end of practice the leg sometimes gave way under him, and he found from time to time that he was walking flat-footed on the left leg.

Twenty-three days after the last training series an involuntary back kick could be elicited.

The first modified response of subject Bm appeared on the ninth day. There was then a lapse in training of 18 days, after which for some time only knee-jerks were obtained in tests. It was noticed in practice that the right leg sometimes kicked back, involuntarily as determined by questioning. Later it tended to move forward, and these kicks were very brisk on a day when he had just run upstairs. He was questioned about a back kick occurring in the last test series, and did not know whether he meant to kick or not.

Subject Cf showed two modified responses, both back kicks, to test blows on the first and seventh days, which she reported were automatic. There was a lapse in practice of 16 days after the eighth day. From the tenth day of practice, the right leg usually also kicked back slightly, more often in the first part of a series. Eight months after the last training series, records were taken with the Johns Hopkins chronoscope, using a pendulum of which the bob weighed, with a contact device on it that was used in the second experiment, 1052.3 grams. For a fall of 21°, the velocity is 87 cm. per second.; for 6°, 25 cm. per second. The break in the front magnet circuit of the chronoscope was made by a momentum device on the pendulum, to be described with the second experiment. The leg kicked against a rubber bulb close to the shin. This was connected by a tube to a pneumatic key, which broke the circuit through the back magnet. The reaction times are obviously lengthened and are of value only for rough comparisons. The knee-jerk records were taken with the number work test as distraction.

A range of 120 to 147 sigma was obtained for 10 left knee-jerks to a blow from 21°. Nine of them were followed by back kicks. Following this series, 16 left forward voluntary kicks were recorded to a left blow of 6°, and ranged from 205 to 253 sigma. This blow was too slow to elicit a knee-jerk. Ten right knee-jerks were recorded to a 21° blow, and ranged from 117 to 160 sigma. The average was insignificantly less than that for the left knee-jerk. Ten right voluntary forward kicks to a right

blow of 6° followed, ranging from 230 to 293 sigma. She said that she found the left forward kick difficult, since there was a tendency to kick back. These records indicate that the knee-jerk was unaffected, but that the habit of kicking back was added. Since the back kick was not timed in practice series so as to eliminate the knee-jerk, it may not have had any inhibiting effect.

About five months later the following records were taken, with a 20-second interval between blows as a rule, and before the series of voluntary back kicks a rest period during which the subject walked down a long hall and back. The blow used was from 18° with a light pendulum bob, for which the velocity is given on page 23. The method and recording were those of the second experiment. During the knee-jerk tests she was reading an absorbing story. The order of the series was: 30 left and 30 right knee-jerks in the order LRRL (15L, 30R, 15L), 41 left back kicks with the preceding knee-jerks recorded, and a second series of knee-jerks in the order LRRL.

A few records are omitted because of anticipations and experimenter's errors. The averages in sigma were: RKJ 77.7, LKJ 76.7, LKJ preceding LBK 100.7, RKJ 81.6, and LKJ 85.1, the medians being slightly less. The LKJ with LBK had a mean variation of 13.4; the others ranged from 2.6 to 7.5, the differences due apparently to the succession of the series. During back kicks, the bar against which the leg rested (described with the second experiment) had to be left off. The different position of the leg when no bar was holding it forward could not cause such an increase as appears in the LKJ with LBK. The first four knee-jerk records following practice were taken without the bar behind the leg so that involuntary back kicks would be possible, but they did not occur. The records were consistent with the rest of the series, and are therefore included in the average.

Since the immediate effect of the practice did not last definitely for more than ten records, the first ten R and L records were averaged separately in the series preceding and following the BK series. The first ten RKJ averaged 78.3, and the LKJ 74.5; in

the second KJ series the average of the first ten RKJ was 79.2; LKJ, 89.9. The mean variations were 2.3, 2.5, 4.6 and 7.3 respectively. The LKJ records are lower in the first series than the RKJ because they were taken first, and the greatest increase seems always to come in the first few minutes of a sitting. In the second series, although taken first, the LKJ records are higher and the range is extended upward, indicating a slowing up due to the back kick practice. This is evidence of a transitory effect of the voluntary practice upon the knee-jerk. It is further evident that the intention of kicking back definitely lengthened the reaction time in the LKJ series with back kicks.

Unexpected tests on subject Df frequently elicited modified responses, some of which were contralateral kicks alone. Most of these seemed involuntary to the subject. Twenty-three days after the end of practice, a strong left kick accompanied right voluntary back kicks made to blows on the right leg. These occurred although she concentrated her attention as much as possible on the right leg. The blows used were of knee-jerk speed and less. Ten months later in a sitting of about an hour and a half, records were taken with the pneumatic system previously mentioned operating the chronoscope. The subject was engaged in composing poetry and managed to keep her attention fairly evenly occupied, although, as happened in all cases, she knew what was going on most of the time. The blow was given from 24° with the pendulum bob and contact device weighing 1052.3 grams. The velocity was 99 cm. per second.

Forty-two left forward kicks reported involuntary were obtained in response to 45 right blows, and ranged from 180 to 315 sigma; then 50 RKJ's to 59 blows, ranging from 98 to 200 sigma. Left kicks occurred with the knee-jerks recorded, and once when no knee-jerk was elicited there was a violent left kick. The left kicks showed no approach to reflex reaction time. The apparatus probably exhibited a greater lag in the case of small knee-jerks, causing times up to 200 sigma.

The first and only left kick without a knee-jerk in tests on subject Ef was elicited on day 9; other modifications appeared earlier. There was then a lapse in practice of 18 days, followed

by a decrease in the number of modified responses to tests. They increased again, but toward the end of practice the kick of both legs became less frequent. She stated on the first day that she could not kick the left leg without deadening the right, but her knee-jerks were at least as frequent as those of any other subject. One test kick of both legs she reported to be involuntary.

Forty-two days after the last day of practice, no modified responses could be obtained either before or after a training series, which was given with a mechanical system in use for operating the chronoscope. Seven months later, records were taken with the pneumatic system in use, and the pendulum bob weighing 1052.3 grams, as for subject Cf. No recordable knee-jerks nor involuntary left kicks could be obtained either before or after voluntary practice, probably because of the insensitivity of the apparatus, although they appeared during the voluntary practice series. A range of 178 to 220 sigma was obtained for a voluntary LFK to 22 right blows, some from 21° and some from 6°; and of 200 to 377 for a voluntary RFK to 20 right blows from 21° and 6°. Only the usual effect of reaction time practice is evident in the difference between the series.

Knee-jerks were obtained with the voluntary left kicks to a right blow. With the first, second and tenth voluntary right kicks, left kicks occurred. She was told that she had no recordable knee-jerk. Subsequently, two very small left kicks were obtained with three blows to the right leg, while she was attempting to 'relax' or allow knee-jerks to occur. The left kick may be said to have become in some degree habitual.

Subject Fm received much less practice than those discussed above. Five of the kicks of both legs, elicited in tests, occurred on the ninth day, just after a lapse of 73 days. Kicks elicited by unexpected blows in the first few days had, however, been suspected of being voluntary or at least expected, since Fm appeared to be interested in what the problem might be. He might also have misunderstood the instructions and thought that he should kick although no ready-signal had been given.

The kicks of both legs of subject Gm elicited by test blows appeared only toward the end of training, on the thirteenth and

fourteenth days. On the sixteenth day, to an accidental blow following the first number work, he kicked the left leg. He said he did not know why he kicked, and the kick may have been involuntary.

There appeared to be a greater and more lasting automatization of the practiced response in the subjects, Am and Df, who knew what the hypothesis was. They were also the ones who were not tested much until after considerable practice, and whose practice suffered no lapses. A similar frequency of modified responses appears in Fm, who also may not have been impartial.

Further work was felt to be necessary, employing reaction times for comparing practiced kicks and knee-jerks. It was desirable to find whether the knee-jerk reaction time changed with practice of another response to the blow, and to try practice when the subject could not guess what was the main purpose of the measurements.

VI. SECOND EXPERIMENT

A. Apparatus and methods

The method employed for measuring the reaction times of leg movements was such that frequent practice was possible with the preservation of a record of every response. The Johns Hopkins chronoscope was used, the motor being operated on rectified synchronized 60-cycle alternating current. The unit of measure was $1\frac{2}{3}$ sigma (millisecond). The chronoscope hand was set in motion by a momentum current-break on the stimulating pendulum, and was stopped by a break caused by the foot movement.

The set-up was intended to avoid the difficulties encountered in other devices for measuring knee-jerk reaction times. Dodge finds direct records from the muscle to be the best type, since inertia is reduced to a minimum. Pneumatic recorders are too variable. The difficulty with mechanical muscle-contraction recording, however, is that the contraction curves vary according to the part of the muscle from which the records are taken (9). Contraction curves, moreover, are difficult to measure, because the beginning of the contraction must be determined arbitrarily

for different shapes of curves. The break device used in the present experiment is possibly also subject to this criticism, in that the part of the contraction when the contact broke was unknown, and may have varied.

Dodge was the first experimenter to use a momentum current break device on the pendulum and a current break from the foot, but he recorded the breaks on a kymograph and the latencies of the markers are unknown. As he reported none of the measures obtained by this method, comparisons cannot be drawn with the measures to be reported below. With graphic registration, few records can be taken in a sitting. He did not obtain more than 22 records on any one point (9).

The present records had to be taken from the foot because no accurate break device could be found for use on the muscle. One highly sensitive device was contrived, but proved inadequate because the mechanical effect of the tendon blow caused a break.

A pendulum, as Dodge mentions (9), is the best hammer because the blow strength is measurable. The one used for stimulation in the present work was operated as in the first experiment, with a more accurate scale graduated in units of 2°. The error in dropping it reached 1° rarely. Fastened across the tendon was a flexible rubber rod of slightly smaller diameter than before, $\frac{13}{32}$ inches. A lighter pendulum bob was used except where otherwise noted. With the contact device mounted, it weighed 430.2 grams. The velocity at the lowest point of swing was calculated in cm. per second, by the formula previously given, for each angle of fall used, as follows: for 4°, 17; 6°, 25; 8°, 34; 10°, 42; 12°, 51; 14°, 59; 16°, 67; 18°, 75; 20°, 83; 22°, 91; 24°, 99; 26°, 107; 28°, 114; 30°, 122; 32°, 129; 37°30′, 148. The use of the heavier bob increased the momentum and energy of the blow, but not the velocity, which with a pendulum of this description seems to be the major factor.

The contact break device on the pendulum was a vertical lever pivoted at the top. It was held against a contact by a coil spring. When the pendulum hit the knee, momentum caused the contact to break temporarily. In the circuit that started the chronoscope was the break device and a balanced relay which

remade the circuit, shunting out the break device. A silk cord, attached to the back of a tape around the narrowest part of the

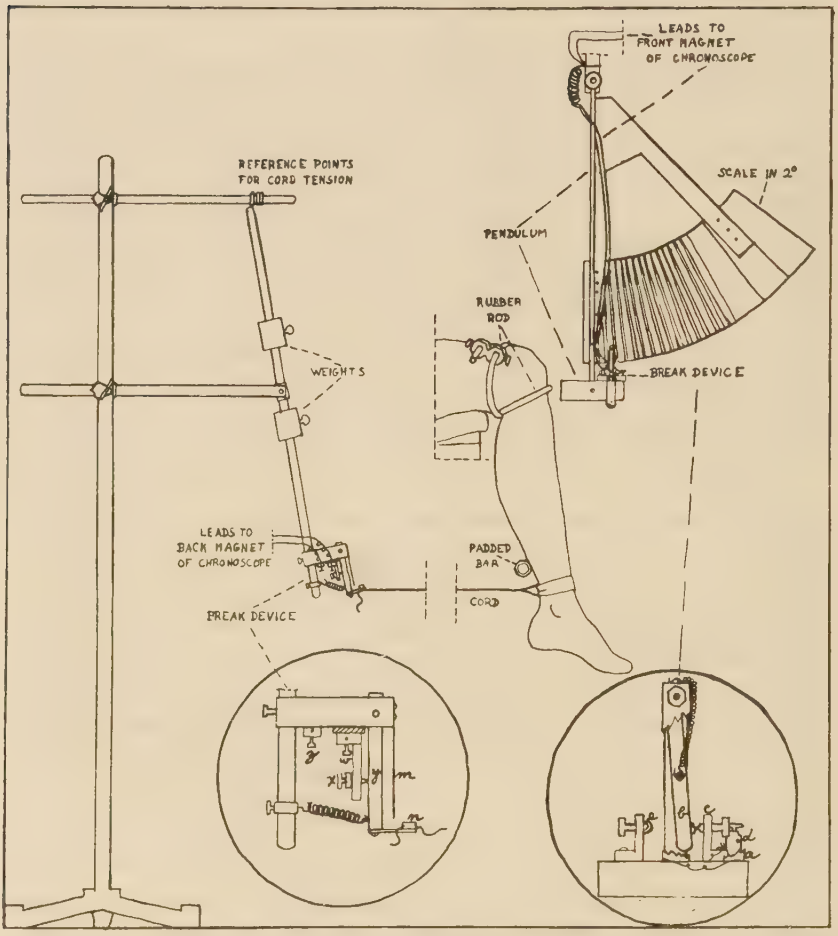


Fig. 1. Essential Parts of the Apparatus

Left inset 0.2 actual size, right inset 0.4 actual size

a, binding post (in part omitted); *b*, contact lever (near upright in part omitted); *c*, contact; *d*, binding post; *e*, rubber stop for lever; *m*, steel spring stop for lever; *n*, set screw for cord adjustment; *w*, binding post; *x*, contact; *y*, contact lever; *z*, binding post. Circuits: *abcd*, *wxyz*.

subject's ankle, was connected to another break device, in the circuit that stopped the chronoscope. This was a lever pivoted

at the base of a compound pendulum bearing weights above and below its fulcrum. The lever was held back against a contact by a coil spring. The weights, the spring and the tension of the cord were adjusted so that a quick forward movement of the foot broke the contact but a slow one did not, the whole pendulum moving with the foot in the latter case. For each subject the string tension was adjusted so that the slight mechanical movement of the leg due to the tendon blow just failed to break the contact.

The current through the chronoscope magnets was made equal by a shunt resistance across each of them. The balanced relay had always one magnet in each of the chronoscope magnet circuits.

The chronoscope and balanced relay were enclosed in a felt-lined wooden box with a window in the front. This diminished the sound of the clicks considerably. For a masking noise a relay was used, connected to a contact on a vibrating reed. This gave a continual clicking sound which was present during all the sittings for which records are reported. The experimenter could still hear the chronoscope clicks, but every subject claimed that he could not, when at the end of the experiment he was asked how the clicks varied. The faster blows were audible, but this could not be avoided.

The subject was seated on a table on a chair cushion raised at the forward end, and raised more at the sides to prevent lateral movement of the legs. Curtains were drawn before him and there was a board on which to rest books or papers. The final set-up included a wooden back rest adjustable as to position and angle, and there was a padded bar behind the subject's legs just above the ankle. The bar was horizontal, and was moved forward so that the legs rested against it, thus keeping them in a constant position and preventing the jar of the blow from moving the ankle. The exact position of the bar was not important, as it could not affect the position of the leg appreciably. It has been said that passive extension of the knee does not affect the mechanical knee-jerk reaction time (60). The subjects' shoes were removed during all the series for which records are reported,

except for subjects 3f and 6f, who never wore heavy shoes. Their feet swelled uncomfortably if shoes were left off. Hose were removed or rolled down or not, according to convenience. The trouser leg was rolled up when the leg was to be percussed. When the subject was kicking voluntarily, a rubber bulb was placed about a half an inch before the shin to break the force of the kicks.

Sittings rarely lasted over an hour. During this time the subjects' legs in rare instances became a little numb, but they never considered the discomfort sufficient for complaint. The fact may bear on the decrease apparent in the jerks, along with other factors previously discussed, since, according to Tuttle, when the leg actually "goes to sleep" the jerk may be depressed (55).

The set-up was in the corner of a large room in which, frequently, another person familiar to all subjects was quietly working. Other people sometimes entered, but almost never could see or be seen by the subject, and there was sometimes audible conversation. The subjects were almost never disturbed by such occurrences, which were probably minimized by the clicking relay. When records were being taken for comparison of the right and left knee-jerks, special care was taken to keep conditions constant and the room quiet.

The subjects could not fail to know from which foot records were being taken and to which leg the blow would be given. Since it took a few minutes to adjust the pendulum, all blows were given to the right leg except when left knee-jerk records were necessary. The right leg may have become more accustomed to the attachment of the rubber and to the blows. The effect of this procedure on the knee-jerk reaction times is not ascertainable.

No records of the monthly cycles of the women subjects were kept, since their effect on the reaction times measured is not known. It is probably variable, judging from work on extent (30).

Subject 7f was tested for the effect of the time interval between knee-jerk blows, in sittings of an hour and a quarter on two

successive afternoons. She had previously had one sitting in the set-up and was not used in any other part of the experiment. She was occupied in reading short stories. In the first sitting 127 blows were given from 26°. Sixty records were obtained with a stimulus interval of 40 seconds, followed by 10 at 15 seconds. In the second sitting 252 blows were given from 26° and the following series of records obtained: 60 at 15 seconds, 11 at 40 seconds, 33 at 20 seconds, 11 at 15 seconds, 17 at 25 seconds, and 14 at 15 seconds. No significant differences were visible in the distributions of reaction times. It was further noted that no change in time interval, and no lapse of a minute or more during which adjustments were made, affected the reaction times. The first two records following 17 such changes were found to fall evenly through the distributions. Where definitely wide kicks were seen, the reaction times fell at the short end of the distributions. Of these there were 13.

Subject 3f was tested on January 22 with 109 blows from 18°. Twenty-two records were obtained at a 15-second interval, 33 at 20 seconds, and 10 more at 15 seconds, showing no difference in the effects of the two intervals.

The frequency of knee-jerks decreased in both subjects toward the end of a period. The successive distributions were shifted toward slightly longer reaction times throughout a period. These changes seemed to occur in all the sittings to be reported. A longer series, due to this fact, showed a distribution of reaction times extended at the upper values. The average, compared to that of a briefer series, was increased more than was the median. In a series of order LRRL, such as 15 L, 30 R and 15 L records, the left knee-jerks would be expected to show wider variation than the right, assuming no original difference between the jerks.

It was determined to employ an interval of approximately 20 seconds between blows in all work. This interval was intentionally not kept accurate, but did not vary more than 3 seconds either way except when a temporary stop was necessary. After the last sitting, each subject was asked how regular this had seemed. It seemed fairly regular to 1f and 5f. 3f, 6f and Cf said it was not; 2m supposed it took longer after he gave a knee-jerk than

when he did not. None of them seemed to have given it any consideration.

The period between the ready-signal and the blow for voluntary kicks was varied from 1 to $2\frac{1}{2}$ seconds, the experimenter gauging the time by the clicks of the masking relay. No subject had any idea that this was done, although they all knew, except 3f, that the preparatory period was irregular.

The effect of the initial velocity of the kick on the break of the pendulum that stopped the chronoscope has not been determined, nor has the effect of the tension of the cord. The most sensitive setting was used on 1f, 4m, 5f and Cf. The next was used on 2m, 3f and 6f, and the least sensitive on 4m after the 7th sitting. The distributions of knee-jerk records obtained with 4m show no difference for the two settings.

B. Experiments and results

Records were taken, on subjects 3f, 4m, 5f and 6f, of the responses listed below, for the purpose of comparison. Abbreviations used are given in parentheses. VK is the same as the FK of the first experiment. The series of records were made in the order given, in any one sitting, and this order was reversed on successive experimental days so that it did not affect the averages.

1. Knee-jerk of the right leg (RKJ).

2. Voluntary forward kick of the right leg (RVK to blow R) following a very slow (i.e., small pendulum-angle) tendon blow. This blow was just quick enough to be easily perceptible.

3. Knee-jerk of the right leg while the subject was making a voluntary forward kick of the left leg in response to a blow on the right leg (RKJ with LVK).

4. Voluntary forward kick of the left leg to a blow, on the right leg (LVK to blow R), of knee-jerk speed. This is just like response 3 except that the records are taken from the other leg. The blow used was definitely above the threshold speed for knee-jerks.

5. Voluntary forward kick of the left leg to a very slow blow on the right leg, of the same speed as was used for response *2*.

The determinations of the threshold of any subject were never very accurate when only a few blows were used. In cases where they were accurate, the data are considered under *Blow speed and reaction time.*

Further practice was given subjects 3f, 5f and 6f in responses *4* and *5*, with records also of *3*. Practice was given subjects 1f, 2m and 4m in response *2* with faster blows. Further knee-jerk tests were made. Table II is shown for reference.

Instructions were formulated and typed, and the appropriate set was read by the reactor immediately before each series, as follows:

1. You will be given a series of blows on your right knee. Before each blow I shall say "ready," and immediately after each blow you

TABLE II

Total practice

SUBJECT	LVK TO KJ BLOW R	LVK TO DEFINITELY SUB-KJ TOUCH R	RVK TO DEFINITELY SUB-KJ TOUCH R	RVK TO MODERATE BLOW R
1f				1511
2m				1669
3f	563	219	1291	
4m	339	121	120	748
5f	1657	681	196	
6f	2043	848	245	

are to kick the right leg forward as quickly as possible. Keep in mind what you are to do: at each blow on the right leg that is preceded by a "ready" signal, kick the right leg forward as quickly as possible.

2. You will be given a series of blows on the right knee. Before each blow I shall say "ready," and immediately after each blow you are to kick the left leg forward as quickly as possible, keeping your attention on the left leg. Keep in mind what you are to do: at each blow on the right leg that is preceded by a "ready" signal, kick the left leg forward as quickly as possible.

3. You will be given some number work to do. Work continuously and aloud, paying attention strictly to the number work. Start when I tell you and continue until I tell you to stop.

The number work test, carefully explained to the subjects, was used as a distraction except when extended knee-jerk records were taken; in the latter case the reactor being instructed to keep his attention on reading matter and to pay no attention to his legs.

A few unexpected test blows were employed, but as the subjects expressed no surprise that kicks occurred, they must be classed as voluntary.

The subjects were asked after the last sitting what they knew about the purpose of the experiment. They mentioned the fact, which the experimenter had originally told them, that comparisons of voluntary and reflex reaction times were being made. Subject 4m had heard the title of the problem before the last sitting, but could not say what he thought the results should be. Subject 2m did know that an attempt was being made to obtain a better knee-jerk but considered this incidental.

Details of the work will be discussed separately for each subject, with tabulation of the records. Individual records were taken to the nearest sigma. Records for certain responses are not included, as follows: (*a*) cases when there was no response large enough to stop the chronoscope; (*b*) anticipations, wherever the subject noticed them, or where the records were well below the range of other reaction times; (*c*) cases where the experimenter or subject made an error, or if there was some definite disturbance of the subject. Records of both classes (*b*) and (*c*) are probably still included in the records presented, as it was desired to avoid the selection of results in so far as possible.

Subject 1f. 1f reported at the same hour every afternoon. She showed no knee-jerks without facilitation, but kicks slower than knee-jerks occurred when she was tested, while reading short stories. They will be referred to as 'imitation knee-jerks,' and occurred even after she was informed that her knee-jerk was all right, that it was natural for it to disappear while she was resting. As she was a foreigner who had not been speaking English many years, there is a possibility that she did not understand very well. On the last day, she was asked why it was bad

not to have a knee-jerk, and replied that it was indicative of one's mental state.

On March 5 and 6, to 92 right blows of from 16° to 32°, 32 records were obtained ranging from 102 to 1060 sigma, with an average of 379.3, and mean variation of 120.2. The Jendrássik handclasp was tried with one blow each at 20° and 18° and 2 blows each at 16° and 14°. Two records were obtained, with 16° and 18° blows, of 92 and 93 sigma. Only one imitation jerk was recorded in this series.

She was given practice in a RVK to a R blow definitely too slow at the beginning to elicit any knee-jerk. The data are in table III. Anticipations were difficult to count and are probably underestimated. They averaged 2 per cent of all the kicks, while other subjects' were less than 1 per cent. They decreased in frequency for all subjects with practice. Four of 6 on March 6 occurred soon after she learned that the apparatus measured time. No other subject was so naïve. A total of 25 records of less than 95 sigma are included on March 7 and March 12 through 23, and 59 records between 95 and 113 sigma. It is difficult to determine whether these and higher records were anticipations or knee-jerks. Many of them definitely were not anticipations, as far as the eye could tell, as kicks succeeded them. The preparation to kick should have been sufficient facilitation for knee-jerks to occur, as from March 9 the experimenter noticed that she almost always contracted her muscles after the ready-signal so that the leg moved visibly. When questioned on March 23, she said that she did not feel any knee-jerks during voluntary practice, but this does not mean that they did not occur. It is probable that knee-jerks could occur more easily after she became used to the experiment. The earlier long times are sometimes due to distraction, as she suffered from a cold until March 9. On March 7 and 8 there was considerable disturbance from a tapping experiment.

The mean variation for the RVK ranged from 9.6 to 32.1. The median on March 15 was 137. On other days it was close to the average.

TABLE III

Note: In all the following tables, the average value in sigma is given, with the number of records for each average in italics.

	RVE TO BLOW R 10°	IMITATION KJ		RVE TO BLOW ON L HAND	
		Right	Left	18°	10°
Total range	65–708	98–745	125–820		
Second series, March 6	*98* 190.5				
March 7	*128* 190.6				
March 8	*128* 181.6				
March 9	*130* 163.7				
March 12	*130* 154.8				
March 13	*150* 155.4				
March 14	*150* 135.1				
March 15	*130* 153.1				
March 16	*150* 133.0				
March 19	*133* 125.0				
		10°–32°	10°–32°		
March 20	*20* 86.8	*70* 242.2	*70* 246.1		
		2°–8°	2°–8°		
March 21	*21* 127.8	*16* 413.8	*12* 378.5		

TABLE III—*Concluded*

	RVK TO BLOW R 10°	IMITATION KJ		RVK TO BLOW ON L HAND	
		Right	Left	18°	10°
March 22	*40*			*20*	*20*
	126.1			147.6	158.5
March 23	*39*			*40*	*40*
	120.9			156.5	151.0

On March 20 the knee-jerks were tested while she was reading, in the order RLLRRL, following a series of RVK's. The same procedure was carried out on March 21, except that the KJ order was LRRLLR. On both days the blow speeds were the same for corresponding R and L series. On March 21, a large number of slow blows were given in sequence and in alternation with faster blows. The kicks persisted at irregular intervals even at 2°, where the records had to be omitted from the average since the chronoscope was not started. She knew that she kicked to these blows, and the experimenter suspected that the kicks occurred to those blows which happened to be noticed. She stated that on these days she succeeded much better in concentrating on her book than in the tests of March 5 and 6. Both legs failed to respond to 1 per cent of the blows of 10° to 32°. The R leg failed to respond to 21 per cent of the blows of 2° to 8°, and the L leg, to 72 per cent.

The habit or, at least, convention, of kicking the right leg appears to be the chief effect of the practice, when the frequency of kicks is compared to that of March 5 and 6, and this 'habit' transferred to the faster blows on the left leg. Whether it was a true automatism could not be determined from her confused replies to questioning after the March 20 sitting. At this time the experimenter told her in simple terms that the kicks were mostly of voluntary reaction time, and that voluntary kicks might inhibit the knee-jerk. That the results were the same on March 21, means either that she did not understand, or else that the kicks were involuntary.

For comparison with other reaction times, on March 22, reactions of the practiced leg to blows on the right hand were recorded. The same procedure was used for all numbered subjects. The hand, wearing a large work glove, was laid on a horizontal metal bar at right angles to the forcarm, with the middle phalanx of the middle finger about vertical. The pendulum hit this member. The slowest blow which would cause the momentum break to act was in this case 10°. The fact that a blow of 4° to the knee was large enough indicates that the glove broke the force of the blow. In all such series, the rubber rod was left on the tendon, in order to keep the conditions as much like those of other series as possible. The faster blow used was chosen so as just not to be painful.

The order of these series was: RVK to a blow on the R leg of 10°, and to a blow on the L hand of 10°, 18°, 18° and 10°. The order on March 23 was the same except that the blows on the L hand followed the order 18°, 10°, 10°, 18° 18°, 10°, 10°, 18°. The data for all subjects are discussed after consideration of each subject. The variability in the records may have been increased by the fact that the hand changed position, varying the effect of the blow. This did not occur with the other reactors.

Subject 2m. 2m appeared to have no knee-jerks without strong facilitation, after the first few blows. He had become used to the experimental situation before January 23, when a right knee-jerk could not be obtained even with facilitation with a blow from 22°. This lack is not explained by the fact later volunteered that he had been kneeling to do carpentry, which made his right tendon sore, for he said that the blows were not painful. The effect of discomfort is at any rate doubtful, as pain has been stated to increase the knee-jerk (35) and to inhibit it if the knee-jerk follows the pain (1, 61, p. 30). He was practiced with a RVK to a blow too slow at first to elicit a knee-jerk. When the RKJ was tested it preceded the RVK series, 10 blows being given each day from February 13 to 24. The data are presented in table IV.

The m.v. of the RKJ series up to the second series of February

TABLE IV

	RKJ	LKJ	RVK TO BLOW R 22°	RVK TO BLOW ON L HAND	
				8°	12°
Total range	98–167	100–135	90–440	140–277	150–262
January 23			*101* 239.0		
	22°–30°				
January 24	*6* 129.5		*100* 202.4		
January 25			*100* 174.4		
January 26			*96* 177.6		
January 29			*100* 180.2		
January 30			*100* 182.1		
February 1			*98* 185.0		
February 2			*49* 186.2		
February 7			*101* 189.5		
February 9			*100* 190.7		
	14°-26°				
February 10	*15* 119.8		*99* 203.4		
	16°–26°				
February 12	*11* 115.5		*100* 185.5		

TABLE IV—*Concluded*

	RKJ	LKJ	RVK TO BLOW R. 22°	RVK TO BLOW ON L HAND	
				8°	12°
	22°				
February 13	*4* 128.0		*100* 168.0		
February 14	*6* 124.2		*100* 170.8		
February 16	*9* 112.9		*98* 161.4		
February 20	*10* 128.4		*99* 166.4		
	22°				
February 21	*3* 122.3		*35* 180.3	*35* 181.3	*35* 183.6
February 23	*0*		*35* 173.0	*35* 173.0	*35* 182.7
February 24	*6* 124.0		*35* 174.2	*35* 183.5	*35* 181.9
	22°, 26°	22°, 26°			
February 24, 2nd series	*6* 124.2	*4* 121.5			
	22°, 26° 37°30′	22°, 26° 37°30′			
April 7	*3* 125.3	*4* 114.5	*40* 179.4		

24 was 4.3 to 12.1, and of the RVK to blow R, 9.4 to 21.8, with the exception of February 2, when it was 31.5. The subject was in poor health on this day. The m.v. decreased generally with practice. The range of the RVK records is noteworthy. Knee-jerks could be seen to occur before the RVK's sometimes, al-

though he was unaware of them, as was determined from questioning after the last sitting. Some anticipations may be included in the records. Records below 140 sigma were considered to be of knee-jerks, as there was a separation in the distributions at that point. Such records decreased in frequency of occurrence beginning February 14, as also did the RKJ on February 21 and 24. The total number of these records was 91. The proportion of 22° RKJ blows to which no response was elicited between January 24 and February 24 was 40 per cent.

On January 23, six R blows of 22° to 30° were given following the RVK series, the subject reading, but no knee-jerks were elicited. The threshold varied as follows: on January 23 and 24 occasional jerks were elicited above 22°. On February 10 the threshold was lower, but when most of the knee-jerks occurred he was working loudly and unevenly at the number work, and the threshold rose when he began working smoothly. Jerks were sometimes obtained at 14° and over, and almost always at 20° and above. On February 12 these thresholds were 2° higher. In the final tests of February 24, the threshold was not appreciably changed, no jerks being elicited below 20°.

The second series on February 24 followed a rest period during which he walked down a long hall and back. He was reading a historical book on psychology. 40 R and 40 L blows were given from 22° in the order RLLR, and then 10 each from 26° in the order RL. Blows were also given from 20° while he read aloud, with no responses recordable. The RKJ m.v. was 5.8, and the LKJ, 5.0. On April 7, a total of 60 blows was given to each leg using three speeds, in two series of order LRRL, with between them a series of RVK's to blow R. The RKJ m.v. was 1.8, the LKJ 13.0. Not enough records could be obtained to compare the two legs on either February 24 or April 7.

In all tests on 2m, knee-jerks were elicited in practically no case except when he was moving or had just made a movement, such as turning a page. This subject made himself as comfortable as possible, and probably relaxed considerably while reading. No change in the right knee-jerk due to the practice could be detected.

TABLE V

	RKJ 20°	LKJ 20°	RVK TO BLOW R 4°	RKJ WITH LVK 20°	LVK TO BLOW R		RKJ TO FIRST 10 BLOWS 20°
					20°	4°	
Total range.....	75–142	82–138	138–632	78–138	148–443	148–462	
January 23, 24....	*40* 107.5		*40* 211.9	*40* 107.4	*40* 239.9	*40* 235.1	*10* 102.7 *
January 25, 26....	*40* 111.5		*40* 220.8	*40* 102.9	*40* 201.3	*40* 230.5	*10* 103.6 *
January 27, 29....	*40* 100.9		*40* 209.2	*40* 106.0	*40* 191.4	*40* 217.1	*10* 90.3
January 31, February 1.....	*40* 92.1		*40* 223.8	*40* 106.7	*40* 181.1	*40* 204.0	*10* 93.9
February 3, 5.....	*40* 93.1		*40* 210.9	*28* 105.9	*40* 175.3	*40* 217.0	*10* 86.5
February 6.....	*20* 96.2		*20* 193.2	*13* 109.4	*20* 197.7	*18* 231.2	*10* 94.8
February 7.....	*15* 97.9		*100* 198.1				*10* 97.5
	14°–20°						
February 9.....	*18* 97.9		*90* 206.0				*2* 85.0
February 12.....	*6* 98.2		*100* 187.2				*2* 82.5
				RVK TO BLOW ON L HAND			
	20°			12°, 14°	8°		
February 20.....	*10* 79.8		*96* 200.8				*10* 79.8
February 21.....	*10* 87.1		*35* 200.5	*35* 202.5	*35* 211.3		*10* 87.1
				14°			
February 27.....	*10* 87.4		*35* 190.0	*35* 206.3	*35* 209.7		*10* 87.4

* Preceded by KJ series.

TABLE V—*Concluded*

	RKJ 20°	LKJ 20°	RVK TO BLOW R 4°	RVK TO BLOW ON L HAND		LVK TO BLOW R	RKJ TO FIRST 10 BLOWS 20°
				14°	8°	4°	
March 1			*32* 197.8	*35* 198.6	*35* 202.6		
March 2	*20* 85.2	*20* 89.9	*38* 195.2	*35* 202.0	*35* 212.0		*10* 80.8 *
March 3	*15* 114.7	*21* 100.2	*20* 200.9				
	12°–18°	14°–18°					
March 2, 3	*16* 105.9	*6* 116.8					

* Preceded by VK series.

The first series on February 24 was made in the order: RKJ, RVK to a blow on the L hand from 12°, then from 8°, and to a 22° blow on the R leg.

Subject 3f. 3f did not, in November, appear to have a knee-jerk, except with facilitation, after the first few blows. She was given five sittings with a total of 544 RVK's to a R blow of 12° to 22°, of which 532 were at 16°. The pendulum bob and contact in use weighed 1052.3 grams.

There was no practice effect visible in the records after the first two days. From December 14 to January 22 there were no sittings. On January 22, while she read a novel, the R knee-jerk could be easily obtained with the pendulum bob and contact weighing 430.2 grams. There is no explanation for the appearance of the knee-jerk, and it may rather be considered an effect of the vacation than of the previous practice. Records were taken, chiefly with a 20° blow, at 15-second and 20-second intervals. In the first series, January 23, the R threshold was determined first with the heavier hammer and then the lighter, and was found to be the same, 16°, for both series, except that not quite so many knee-jerks were elicited in the second series. The appearance of the knee-jerk was therefore not due to the use of a lighter hammer.

Threshold tests were made on January 22 as well as 23. The RKJ to blows of 14° to 26° averaged 106.6 sigma for 94 records. Forty-one per cent of the blows elicited no recorded KJ. On January 23, a second series was made, shown in table V. The effect of the voluntary practice of January 23 and 24 should be negligible in a KJ series on January 25, taken in the order LR, with 8 blows of 14° to 22° to each leg, while she read. The averages, not shown in table V, were: 7 LKJ, 89.7 sigma; 7 RKJ, 103.0; the m.v.'s both 2.9. The thresholds were the same, there being no records made below 16°.

The R-L difference is not entirely due to the order of the series, for in other, RKJ, series at the beginning of a sitting the difference between the averages of groups of records in positions in the series corresponding to these R and L records was only 1.0, 3.0, 6.8 or 7.9. The net difference, by subtracting the average of these, would be 8.6.

The average RKJ became quicker and less variable than the RKJ with LVK from the January 27–29 average onward. The RKJ m.v. was 5.4 to 10.1 for the six averages to Feb. 7, and the m.v. for the RKJ with LVK was 8.8 to 12.3. The proportion of RKJ blows to which no response was recorded in these 11 sittings was 4 per cent, and of RKJ with LVK, 45 per cent. The RKJ with LVK practically disappeared on January 26 and February 5, and became infrequent on February 6. The LVK to a 20° blow was usually faster than that to a 4° blow, but this difference was not marked. As she did not kick as hard as she could, the following variations are not surprising. The m.v. of the RVK to blow R on these days was 19.3 to 30.9; of the LVK to a 20° blow R, 10.7 to 33.5, but usually less than that for the RVK to blow R; and of the LVK to a 4° blow R, it was 12.9 to 36.7. The LVK to both blows decreased in variability with practice, while the RVK did not show so much decrease, as it had been practiced previously.

During practice beginning February 7 the knee-jerk series always came first. No significant change in the RKJ appears in these series. The threshold was found on February 9 and 12 to be still 16°, with, on February 9, occasional jerks elicitable at

14°. Averages of RKJ's occurring to the first ten blows in sittings when tests of them were made first beginning with January 23, with a 20° blow, are given at the right of the table. The changes are as likely to be due to the time of day, early afternoon giving the quickest times, as anything else. The average time may vary continuously from day to day, without any apparent cause. No trend ascribable to the practice is visible.

On March 2, a second series of tests was made of knee-jerks in the order RL, ending with 10 20° blows in the order LR, with the subject reading. The threshold for the RKJ was slightly lower than that for the LKJ, but this difference is plainly due to the fact that the RKJ threshold test was made first. The same is true of the averages. On March 3, the R and L thresholds were tested immediately after the RVK's, while she read. No right involuntary kicks to a blow of 4° or more were obtainable. The knee-jerk series followed in the order LRRL. In this series the RKJ was slower than the LKJ, and the m.v.'s were 10.7 and 9.2 respectively. The RKJ was also less frequent, there being 52 RKJ blows and 54 LKJ blows, with fewer RKJ records than LKJ. The infrequent and high records are due to the series coming late in the sitting. The R-L difference is greater than the net difference of January 25. The arrangement of the series prevented the testing for any difference immediately following a series. What is seen is possibly a lasting depression due to the practice.

Additional records were made as shown in table V, on February 21 and 27, and on March 1 and 2, when the order of the voluntary kick series was the reverse of that in the table. She said that the 8° blow was so light that it touched only the glove.

Subject 4m. Records taken on 4m on February 2 were preceded by a series to determine the RKJ threshold. No jerks were elicited below 18°, and they usually occurred at that speed and above. Comparison series were made on six days, for which the data are in table VI. No practice effect is visible. For an unknown reason the LVK to blow R became slower, that to a 20° blow becoming more variable. The m.v. of the RVK to a 4° blow R was lowest for the February 9–12 average, and ranged

TABLE VI

	RKJ	LKJ	RVK TO BLOW R 4°	RKJ WITH LVK 20°	LVK TO BLOW R	
					20°	4°
Total range	80–155	87–162	125–285	90–157	98–273	133–230
	20°					
February 2, 3	*29* 103.5		*40* 180.3	*25* 114.8	*40* 143.6	*40* 166.4
February 5, 6	*31* 113.2		*40* 183.6	*18* 118.2	*39* 145.0	*40* 164.6
February 9, 12	*28* 105.8		*40* 184.4	*18* 125.3	*40* 178.6	*40* 178.0
	20°–28°	22°–28°				
March 5	*12* 126.6	*12* 128.4				
	18°–32°	18°–32°				
March 6, 7	*97* 110.7	*75* 119.0				
			RVK TO BLOW R			
			14°	16°		
Total range			85–350	103–265		
March 8			*60* 161.1	*42* 146.7		
March 9			*100* 164.5			
March 12			*100* 161.0			
March 13			*100* 164.2			
March 14			*99* 156.2			
March 19			*101* 151.3			

TABLE VI—*Concluded*

	RKJ	LKJ	RVK TO BLOW R		LVK TO BLOW R	
			14°	16°	20°	4°
	18°–30°	18°–30°				
March 20			*20* 149.7			
March 21	*108* 109.7	*80* 118.8	*20* 152.5			
March 22			*20* 157.1			
				RVK TO BLOW ON L HAND		
				6°, 8°	18°	
March 23			*40* 157.2	*40* 175.3	*40* 163.4	
				8°		
March 24			*40* 148.0	*40* 160.4	*40* 152.2	

from 18.0 to 24.7. For the LVK to a 20° blow R the m.v. was 9.1 to 24.5, and for the LVK to a 4° blow R it was 13.9 to 14.9. The m.v. of the RKJ to 20° was 9.9 to 13.0, and of the RKJ with LVK, 7.0 to 11.3. The m.v. of the RKJ with LVK was less than that of the RKJ except for February 5–6. This is probably due to the fact that RKJ series averaged were from the beginning and end of their respective sittings, while the RKJ with LVK were not. The RKJ with LVK was slower than the RKJ. It practically disappeared on Febrary 3, 6, 9 and 12 and became very infrequent on February 5. There was no response recorded to 72 per cent of the RKJ with LVK blows, and to 50 per cent of the 20° RKJ blows. This difference would appear larger if more blows had been given at a time, as the RKJ never became very infrequent. The RKJ with LVK was definitely and increasingly slower and less frequent than the RKJ alone. The LVK to a 20° blow R was faster than the RVK to a 4° blow R, perhaps because of the greater amount of practice of the LVK.

The thresholds were determined on March 5 with 24 blows to each leg, 4 at each blow speed tried. Jerks were elicited sometimes at 20° for the right leg, and 22° for the left, and usually at 24° and over for both. As the order was RL, the difference between the two legs is negligible.

On March 6, a series of RKJ's with 39 blows was made, but is not reported because there was apparatus difficulty. The tension on the cord from the ankle had to be lessened from this time on, as otherwise the heavier blows broke the contact that it controlled. The series reported was taken in the order RLLR. The order in which the blows of different speed were given was partially equated for the two legs to equalize temporal effects for the blows, and as usual the same number of each speed of blow was given to each leg with one exception. The series on March 7 was in the order LRRL and the blow speeds were mixed in a series of 18 which was repeated in reversed order. There was no response to 25 per cent of the RKJ blows on these two days, and to 41 per cent of the LKJ blows. The m.v. of the RKJ was 11.5, and of the LKJ, 15.6. A consistent difference is visible in the reaction times, frequency and variability.

Practice was given of the RVK to a blow R at first definitely too slow to elicit a knee-jerk. They appeared before the voluntary kicks during practice, however, even after the blow was lowered from 16° to 14°. Only 2 blows were given from 16° on March 9. As a dividing line appeared in the distributions of records at 133 sigma, the records below this figure were counted as knee-jerks. There were 11 of these in the series at 16°, and 21 the rest of the time, with no visible practice effect. The greatest frequency was 9 on March 19. Some slow decrease in the RVK records is visible.

On March 20, 21 and 22, KJ series were taken following the RVK series, and were in the order RLLR, LRRL and RLLR. The order of the blow speeds was arranged to equalize temporal effects, the series on March 21 and 22 being like those of March 7. The R leg failed to respond to 27 per cent of the blows, and the L, to 46 per cent. The LKJ was still the slower of the two and less frequent. The mean variation was 9.6, and that of the

RKJ was 11.1. The series of March 21 and 22 were more regular. They averaged 109.8 for the RKJ, and 117.8 for the LKJ, with medians of 107 and 118, and m.v.'s of 11.5 and 9.2 respectively. The RKJ was not recorded to 23 per cent of the blows of 18° to 30°, and the LKJ to 47 per cent, the RKJ threshold being lower by 2°. The m.v.'s were doubtless influenced by the thresholds, as more R records were obtained with slower blows, and some correlation is visible between blow speed and reaction time.

The difference between the RKJ and LKJ appears to be the same as before practice. If the first few blows following a practice series is considered, the difference is the same.

Records were taken on March 23 in the following order: RVK to a blow of 14° on the R leg, then to 6°, 18°, 18°, 8°, 8°, 18°, 18°, 8° on the L hand. On March 24 the order was: RVK to 14° on the R leg, then to 18°, 8°, 8°, 18°, 18°, 8°, 8°, 18° on the L hand.

Subject 5f. From December 13 to January 19, 5f had practiced the LVK to 115 blows on the R leg from 12° and 16°, and to 230 from 18° and 24°. She practiced the RVK to 115 blows on the R leg from 12° and 16°. A number of other blows were also used in knee-jerk tests. The blows from 12° and 18° were given with the pendulum bob and contact device weighing 1052.3 grams. The other blows were given on January 18 with the bob and contact device weighing 430.2 grams. The apparatus was in its final form on January 19, and records are reported from that day on.

Data from subject 5f are in table VII. It will be noticed that the LVK to 26° R is quicker than either the LVK or RVK to a 4° R blow. This difference was visible from the first day of practice and is therefore not a practice effect. The RKJ is quicker and less variable than the RKJ with LVK. The RKJ m.v. was 6.4 to 19.4; and the m.v. of the RKJ with LVK was 6.0 to 13.0 up to February 12. For the RVK to blow R, 4°, the m.v. was 9.9; for the LVK to blow R, 26°, it was 5.7 to 18.0; and for the LVK to blow R, 4°, 7.8 to 15.0, which was mostly higher than that for the LVK to blow R, 26°.

The RKJ with LVK occurred with continually decreasing

TABLE VII

	REJ 26°	LKJ 26°	RVK TO BLOW R 4°	REJ WITH LVK 26°	LVK TO BLOW R		LVK TO BLOW ON R HAND	
					26°	4°	16°	8°
Total range	70–143 (315)	73–140 (310)	155–213	73–138 (243)	110–642	130–283		
January 19, 23, 24, 25	*80* 91.4		*80* 178.6	*80* 98.9	*80* 140.9	*80* 176.1		
January 26, 27				*63* 103.5	*70* 149.6	*70* 171.8		
February 2, 5				*60* 96.1	*70* 144.5	*70* 182.0		
February 7, 9				*40* 111.9	*55* 139.1	*55* 170.5		
February 10, 12				*37* 88.9	*70* 141.9	*69* 178.1		
February 13, 14				*70* (105.3) Med. 100	*70* 148.6	*70* 181.0		
February 15, 16				*70* (109.5) Med. 103	*70* 148.2	*70* 178.2		
February 27				*35* (114.7) Med. 98	*35* 148.3	*35* 185.7		
February 28	*15* 99.6 Med. 98 & *12* (264.1)	*33* 93.4 93 & *6* (293.0)		*9* (111.6) Med. 90	*10* 134.0	*10* 170.3		
March 2	*34* 98.8 Med. 97 & *1* (277)	*36* 103.1 98		*19* (101.3) Med. 102	*10* 150.9	*10* 205.3		

TABLE VII--*Concluded*

	RKJ 26°	LKJ 26°	RVK TO BLOW R 4°	RKJ WITH LVK 26°	LVK TO BLOW R		LVK TO BLOW ON R HAND	
					26°	4°	16°	8°
March 3.....				*19*	*20*	*20*	*50*	*50*
				(112.8)	145.6	182.0	158.0	162.6
March 28:								
First series.	*21*	*30*		*19*	*20*			
	103.6	99.7		139.7	147.1			
	Med. 100	98						
Second series.....	*5*	*21*						
	95.2	98.6						
	Med. 102	92						
Both series.	*26*	*51*						
	102.0	99.2						
	Med. 100	95						

frequency. It became impractical to obtain the desired number of records in each sitting. This response became infrequent on January 27, February 2, 7, 9 and 14, and practically disappeared on February 10. The proportion of RKJ blows to which no response was recorded for subject 5f is exactly 0 per cent; of RKJ with LVK blows, 48 per cent; up to February 14. This percentage is not reliable for any subject, for when the frequency decreased so much that the desired number of records was not obtained with twice that number of blows, the series was discontinued, while with prolongation of the series the proportion of records would have decreased further.

From February 14, a right leg response appeared, which was sometimes indistinguishable from the knee-jerk, but ranged to kicks with obviously voluntary reaction times. Data including these are indicated in parentheses. Nine records between 277 and 312 sigma were obtained on January 24 and 25, but were not identified as 'imitation knee-jerks' because no kick at all was visible. She remarked on these kicks, and said they were probably voluntary to some extent, since she felt that the right leg ought to be responding. She probably did not recognize very

small knee-jerks. On February 16 this 'imitation jerk' response continued into the series to a 4° right blow, and she apologized. The disappearance of the knee-jerk apparently did not seem to her a necessary accompaniment of the contralateral kick. In this respect she differed from subject Ef.

On February 28, the voluntary kick records were taken first, in the order shown in table VII. Then, while she was reading an illustrated book, 4 test blows from 4°, 2 from 8°, and 4 from 26° were given to the right leg, with recording from the left. No responses of the left leg were elicited. Two blows from 4° and 1 from 8° were then given the right leg with recording from the right leg, with no response.

The knee-jerk series followed, in the order RLLR. On March 2, the records of the RKJ with LVK were taken first, then 15 RKJ records, the first 4 alternated with slow blows to see if imitation knee-jerks would occur to the slow blow; they did not. For a distraction on this day she read a popular psychological book. The LVK records to a 4° R blow and to a 26° R blow were then taken, followed by 8 26° R blows with recording from the L leg while she read. No left kicks occurred. Just before the last blow, the experimenter asked if the breeze was too strong. She guessed why the question was asked, and the distraction had no effect. The rest of the KJ records were taken in the order 10R, 35L, 10R. The records for February 28 and March 2 are reported separately because of the difference in the voluntary reaction times. Some medians are given for this subject because they did not fall close to or just below the averages.

In these series the 'imitation knee-jerks' occurred to both the LKJ and RKJ blows, although no contralateral kicks were being made. Where they were not preceded by KJ's they were clearly distinguishable by their reaction times, and are therefore separately listed. Those of the L leg, however, were less frequent and occurred only on February 28. The RKJ with LVK was no slower than the RKJ, except that the average was lengthened by the imitation jerks. The reason assumed for this fact is that the KJ series were extended, while those with the LVK were not, and relaxation or whatever occurs with time could not take effect.

The LKJ on February 28 was quicker than the RKJ. This may be laid to an actual effect of the voluntary practice. Such an effect was soon lost after prolonged elicitation of knee-jerks. On March 2, the LKJ series was begun at least 20 minutes after the RKJ series was. The longer times that increased the average are thus accounted for. The medians are more significant.

On March 28, she was again tested, the distraction being a book on psychology. The RKJ and LKJ were tested under well equalized conditions. The first series, of order RLLR, was followed by a rest period, during which she walked down a long hall and back, then by the series of the LVK to blow R, and the RKJ with LVK. The second series of KJ's was also of order RLLR, although no jerks could be obtained in the second group of R blows. The 'imitation knee-jerk' did not seem to occur in response to the KJ blows.

The LKJ reaction times on this day were shorter than the RKJ, and the difference increased after practice, as seen from the medians. The reason that the RKJ average was less than the LKJ in the second series may be that there were too few records to be reliable. If the first few R and L blows in test series following LVK practice are considered, the result is more obvious. On February 28, following the LVK series 8 RKJ records were obtained in 20 blows, averaging 104.1 sigma, and then 13 LKJ records in 20 blows, averaging 94.8 sigma. The medians were 97.5 and 95. On March 2, 9 RKJ records in 12 blows averaged 93.0 sigma, and 8 LKJ records in the next 12 blows averaged 114.0, the medians being 93 and 115. On March 28, following the LVK practice, 5 RKJ's in 16 blows averaged 95.2 sigma and 11 LKJ's in the next 16 blows averaged 97.7, the medians being 102 and 92. The medians are more significant for brief series and indicate here a definite difference, except on March 2, when there had been recent extended testing.

The order of series on March 3 was: 10 LVK's to 4° R, 10 to 26° R, then those to a blow on the R hand from 16°, 8°, 8° and 16°; 10 to a 26° blow R, 9 to a 4° blow R, and then the RKJ's with LVK. During the last series she was particularly attempting to concentrate on the left leg, and right 'imitation jerks' were still visible. Test blows were given at the ends of the last three

series. A blow at 4° she noticed was not preceded by a ready-signal, and she did not kick. One at 26° she could not remember afterwards, but she had kicked after 303 sigma. To 3 others, eliciting recorded RKJ's, she gave 2 left kicks. She remarked, after kicking in response to one of the last ones "Oh, you didn't say 'ready'." She said that the kicks she made were not just like those when there had been a ready-signal. These kicks appear to have been automatic, but of voluntary origin, and not similar to reflexes.

The right 'imitation jerks' did not occur when the blow was on the hand. This fact indicates at least that she did not think the leg should move. Certain 'imitation jerks' occurred without her knowledge. On one occasion she expressed surprise at one, when they had been occurring right along. They may be characterized as responses to KJ blows when the subject was not distracted by reading but was presumably paying attention to the other leg, except on February 28 and March 2, when they were carried over temporarily to the reading situation and for a briefer time to the left leg. Although they seemed to originate because of a belief on the part of the subject that kicks should occur, after a time they became automatic.

Subject 6f. 6f reported morning and afternoon at regular hours, and received the most frequent practice of any subject. In the first three sittings, of March 5 and March 6, a.m., records were taken while she was reading. Except for the first ten blows on the R leg, the speeds were ordered to equalize temporal effects. Some blows from 8° and all from 22° were added, mostly at the end of the series. The right and left series were arranged as follows for these sittings: RLLRRL, RLLR and RLLR. 'Imitation knee-jerks' were invariably obtained when no knee-jerk occurred, the reaction times being distinctly longer, and some were seen to follow knee-jerks. The average of 63 R and L 'imitation jerks' was 321.8 sigma, and the range 165 to 642. Records of these for which no movement was visible are not reported. The other records are in table VIII.

The proportion of RKJ blows from 20° to which no KJ occurred was 3 per cent, and of LKJ blows, 6 per cent. Consider-

ing all blows from 10° to 20°, totaling 200 and 204 respectively, the percentages were 43 for the RKJ blows and 33 for the LKJ. The frequency with which KJ's occurred is high for this subject.

TABLE VIII

	RKJ 10°–20°	LKJ 10°–20°	RVK TO BLOW R 4°	RKJ WITH LVK 20°	LVK TO BLOW R		LVK TO BLOW ON R HAND	
					20°	4°	8°	18°
Total range	67–127	68–132	143–323	68–130	112–383	130–483		
March 5; 6, a.m.	*113* 91.4	*135* 91.8						
	20°							
March 6, p.m.	*15* 77.6		*15* 209.5	*15* 82.4	*15* 181.1	*15* 193.6		
March 7, 8, 9, 12.	*239* 79.3		*229* 203.9	*228* 92.6	*230* 161.4	*230* 197.4		
March 13, 14.				*140* 91.9	*200* 161.4	*200* 198.9		
March 15, 16.				*148* 95.3	*198* 160.7	*199* 195.8		
March 19, 20.				*154* 91.7	*200* 166.0	*200* 200.9		
		20°						
March 21, 22.	*197* 93.0	*200* 84.7			*80* 154.4			
March 23, a.m.							*40* 206.7	*40* 193.3
March 23, p.m.					*80* 163.7		*40* 194.1	*40* 186.9

The RKJ median was 88 and the LKJ 83, but there was no difference in the averages, and the m.v.'s were 13.5 and 14.5 respectively.

The order of the comparison series begun March 6, p.m., was

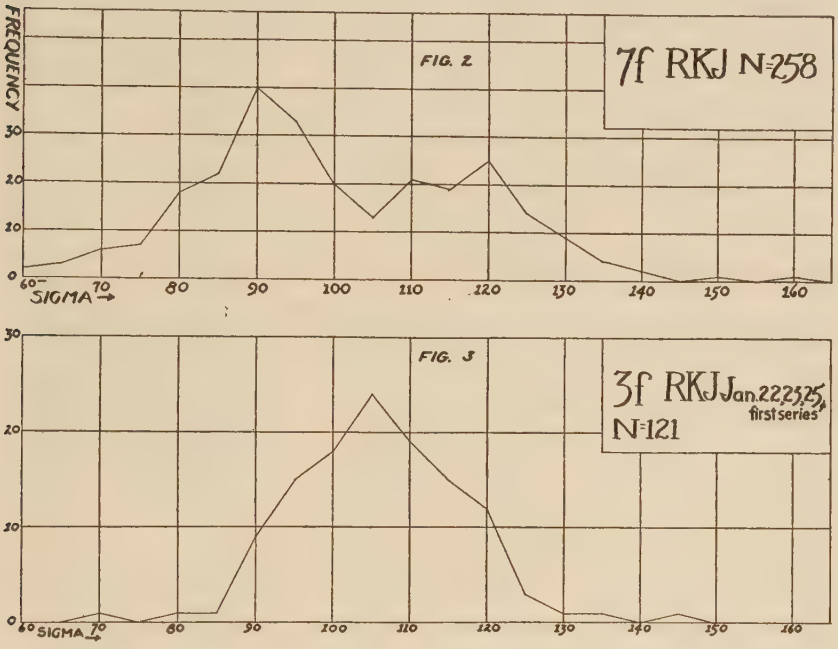
reversed on successive days. No practice effect appeared after March 6. The RKJ m.v. was 3.9 for the short series of March 6, and 4.7 for the average of the next 8 sittings. The m.v. of the RKJ with LVK was 3.1 and 12.3. This response was slower than the RKJ and became more variable. The m.v. of the LVK to 20° R was 10.0 and 17.5; of the LVK to 4° R, it was 6.6 and 25.7; and of the RVK to 4° R, 10.2 and 18.4. The LVK to 20° R was the quickest voluntary kick, that to 4° R the next, and the RVK to 4° R the slowest. The last did not show any relative slowing between March 7 and 12 due to more practice in the L kicks.

Further changes appeared in the RKJ with LVK when only the L kicks were practiced from March 13 to 20. Its m.v. was 13.2 to 13.5, but this kick became very infrequent on March 14, a.m., 15, a.m., 16, a.m., and 20, p.m., and practically disappeared on March 14, p.m., and 15, p.m. The proportion of blows to which no response was recorded was 34 per cent. (The a.m. and p.m. records of the RKJ with LVK were compared for the March 7–8–9–12, 13–14, 15–16 and 19–20 averages. The p.m. records were 3.5 to 5.7 sigma less or on the average 5.0. The percentage of blows to which no response was recorded was in the a.m., 32, and p.m., 24.) The m.v. of the LVK to 20° R was 15.0 to 16.2, and of the LVK to 4°R, 15.4 to 16.6.

On March 21 the order was: LVK to blow R, 2 test blows from 20° and one each of 26° and 30° with recording still from the left leg, while she read. A KJ series followed in the order RLLRRLLR. On March 22 the order was the same except that the KJ series was in the order LRRLLRRL. The LKJ was definitely faster in each of the 4 sittings than the RKJ, by a difference greater than the original difference between the medians on March 5 and 6, and the m.v. of the LKJ was 8.9, and of the RKJ, 10.3, although the LKJ m.v. was the greater for two of the sittings. There was no response to less than .5 per cent of the LKJ blows, and to 3 per cent of the RKJ blows. No 'imitation knee-jerks' occurred. The difference between the two legs was greatest on March 21, a.m., when the RKJ average was 98.5, and the LKJ, 83.4. The first 10 RKJ on March 21, a.m., averaged 100.4 sigma; p.m., 85.3; March 22, a.m., 89.0; and p.m.,

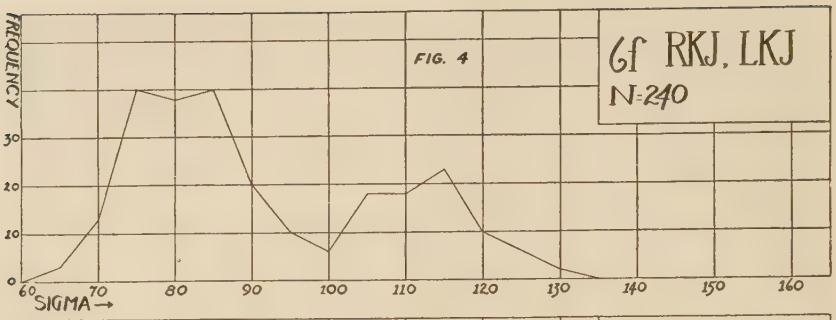
85.8. The first 10 LKJ averaged, in the same sittings, respectively, 73.5, 78.4, 80.5 and 79.3. There was a transitory large difference, due to the practice, which disappeared with extended testing and also a more permanent difference which shows in the averages after March 21, a.m., and which is larger than that originally visible in the medians.

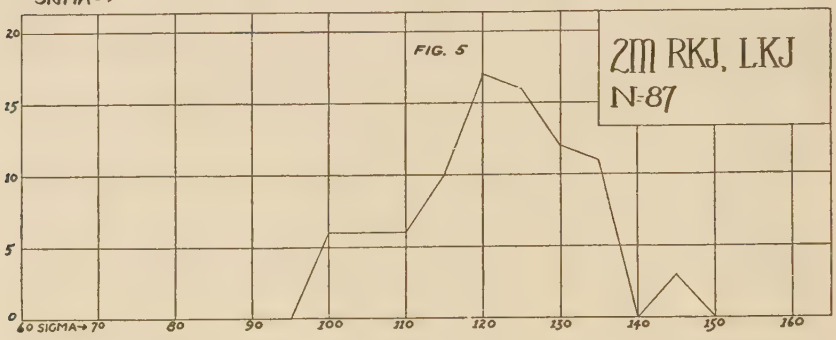
On March 23, a.m., the following series was made: LVK to 20° R, then to 8°, 18°, 18°, 8°, 8°, 18°, 18°, 8° on the L hand.

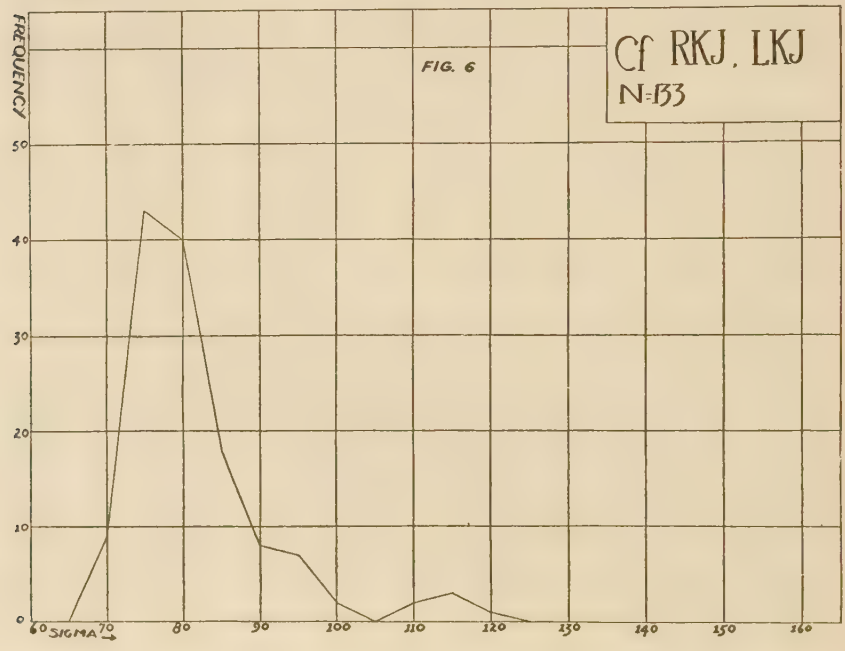


The p.m. series was the same except that the blow speeds to the hand were in the order 18°, 8°, 8°, 18°, 18°, 8°, 8°, 18°.

Blow speed and reaction time. The knee-jerk data in tables IV, VI and VIII can be averaged to show the effect of blow speed. When this is done, using approximately the same number of records at each blow speed, a decrease is visible in the knee-jerk reaction time with increase in blow speed above a certain value for each subject. The change is not, for these few cases, at all regular.


FREQUENCY
0
10
20
30
60
70
80
90
100
110
120
130
140
150
160
SIGMA →
FIG. 4
6f RKJ, LKJ
N=240


0
5
10
15
20
60 SIGMA→ 70
80
90
100
110
120
130
140
150
160
FIG. 5
2M RKJ, LKJ
N=87


FREQUENCY
0
10
20
30
40
50
60 SIGMA→ 70
80
90
100
110
120
130
140
150
160
FIG. 6
Cf RKJ, LKJ
N=133

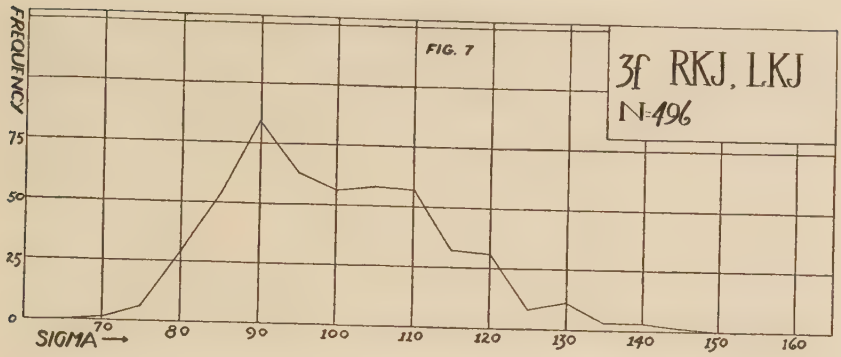


FIG. 7
3f RKJ, LKJ
N=496
FREQUENCY
75
50
25
0
SIGMA →
70
80
90
100
110
120
130
140
150
160

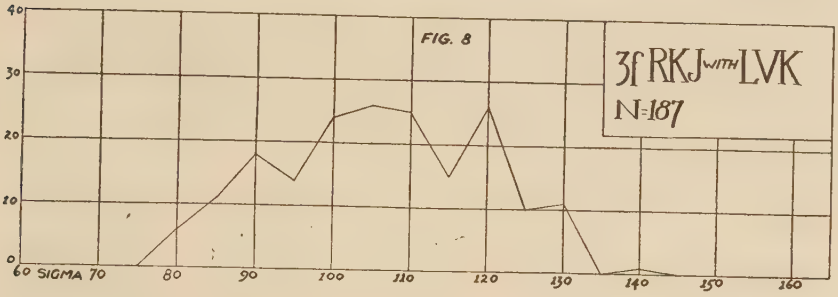


FIG. 8
3f RKJ WITH LVK
N=187
40
30
20
10
0
60 SIGMA 70
80
90
100
110
120
130
140
150
160

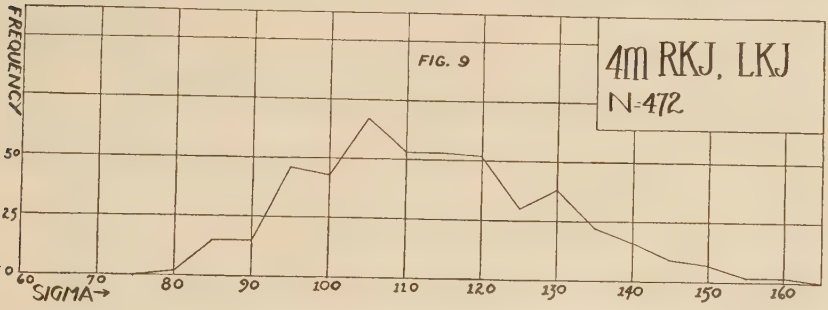


FIG. 9
4m RKJ, LKJ
N=472
FREQUENCY
50
25
0
60
SIGMA →
70
80
90
100
110
120
130
140
150
160

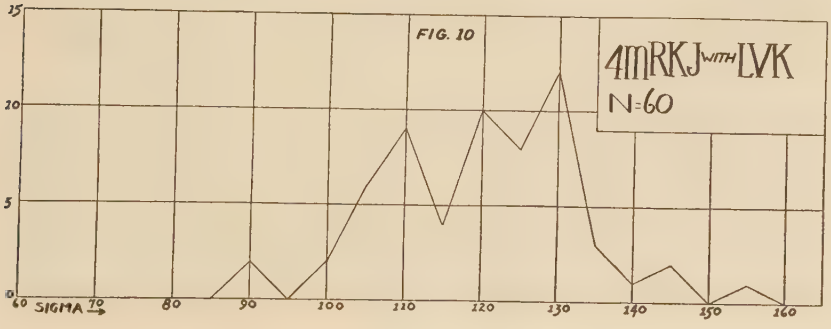


FIG. 10
4m RKJ WITH LVK
N=60
15
10
5
0
60 SIGMA →
70
80
90
100
110
120
130
140
150
160

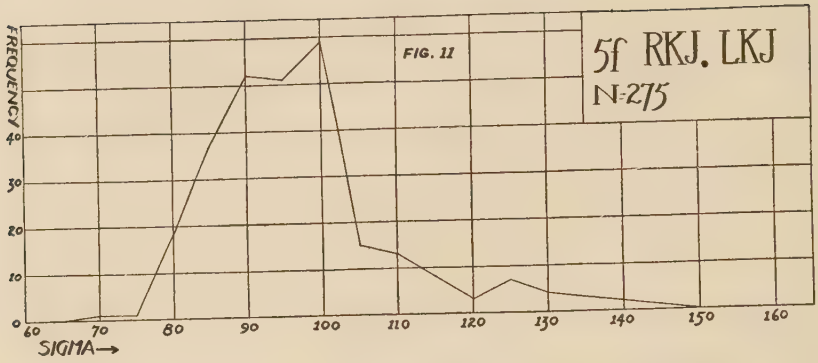


FIG. 11
5f RKJ. LKJ
N=275
FREQUENCY
0
10
20
30
40
60
70
80
90
100
110
120
130
140
150
160
SIGMA→

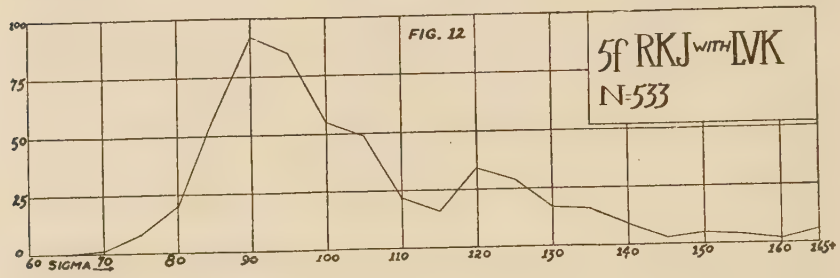


FIG. 12
5f RKJ WITH LVK
N=533
0
25
50
75
100
60
70
80
90
100
110
120
130
140
150
160
165
SIGMA→

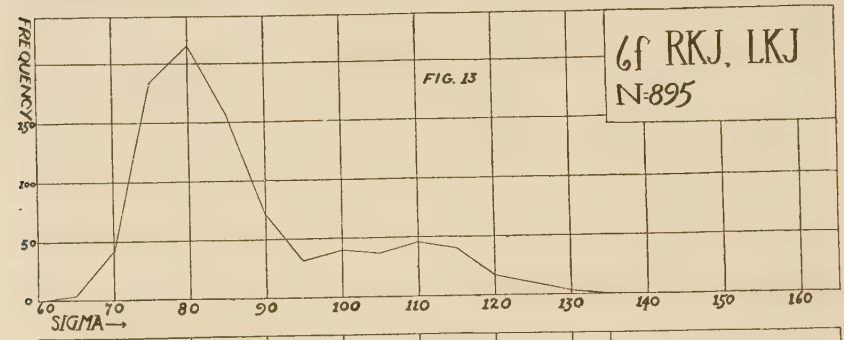


FIG. 13
6f RKJ. LKJ
N=895
FREQUENCY
0
50
100
150
200
60
70
80
90
100
110
120
130
140
150
160
SIGMA→

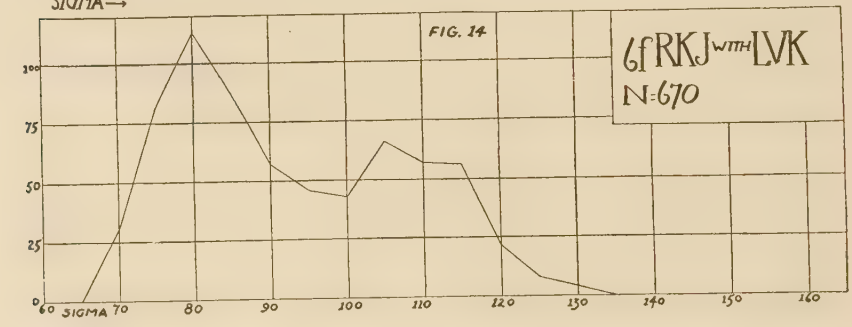


FIG. 14
6f RKJ WITH LVK
N=670
0
25
50
75
100
60
70
80
90
100
110
120
130
140
150
160
SIGMA→

The relation between the weight and speed of the blow does not appear to be the same for all the subjects. The weight of the pendulum did not much affect the speed necessary for 3f and Cf. For 5f, a much faster blow was necessary with a lighter pendulum bob.

TABLE IX

SUBJECT	PRACTICED RESPONSE	M.V.	VK TO SLOW BLOW ON HAND	M.V.	VK TO FAST BLOW ON HAND	M.V.	ALL VK TO BLOW ON HAND	M.V.	NUMBER OF RECORDS IN SERIES
1f	*79* 123.6	11.4	*60* 153.5	21.2	*60* 153.5	17.8	*120* 153.5	19.5	*20, 40*
2m	*103* 177.1	10.8	*105* 179.4	15.4	*105* 182.8	12.5	*210* 181.0	14.2	*35, 35, 35*
3f	*140* 195.9	15.7	*140* 208.9	18.7	*140* 202.4	14.2	*280* 205.6	16.5	*35, 35, 35, 35**
4m	*80* 152.6	11.2	*80* 167.8	9.2	*80* 157.5	16.4	*160* 162.8	17.6	*40, 40*
5f	SLOW BLOW								
	19 182.0	9.4	*50* 162.6	18.4	*50* 158.0	13.5	*100* 160.3	16.2	*50*
	FAST BLOW								
	20 145.6	5.7							
6f	*80* 163.7	11.6	*80* 200.4	21.1	*80* 190.0	18.4	*160* 195.2	20.3	*40, 40*

* Approximate.

Distributions. The knee-jerk records of each subject are placed together in distributions in figures 2 to 14. Some show definite bimodality, which is particularly evident in the reaction times of the knee-jerk accompanying a voluntary kick of the opposite leg. In some, there is a suggestion of polymodality.

Figure 4 includes only records from March 5 and 6, a.m.

The first three distributions show that the bimodality is not necessarily due to any of the following procedures: combining RKJ and LKJ distributions having different central tendencies, combining distributions from one leg which were obtained respectively at the beginning and end of a sitting, with no records from the middle, or including RKJ records after practice of an inhibiting response. The distribution from 3f, however, compared to the two later shown from that subject, suggests that the polymodality visible may be due to such factors.

Data with hand stimulation. Table IX contains the averages obtained for comparison of reaction times to a blow on the knee-tendon with those to blows on another member; the opposite hand. For subjects 1f, 2m, and 4m, the corresponding series of practiced responses consisted of the RVK to a blow that in practice had sometimes elicited knee-jerks (cf. table II). For 2m, the records below 140 sigma are omitted. The practiced response of 3f was a RVK in response to a very slow right blow 5f and 6f had practiced the LVK to a R blow of knee-jerk speed. Their records are of a LVK, therefore. Records are shown for 5f, also, of the LVK to a very slow R blow. The response to a fast blow on the opposite hand was quicker than that to a slow blow, except for 2m; but it was not quicker than the response to a slow blow on the same leg, in subject 3f. The response to either blow on the opposite hand was consistently slower than any practiced response, and this difference was not altered by continued practice of the response to the hand blow (cf. tables IV and V).

VII. CONCLUSIONS

1. It appears that the knee-jerk can be altered by practice in voluntary kicking in response to the knee-jerk stimulus. If one leg is percussed during practice, the effect of the voluntary response is in accordance with the type of response.

(a) If the percussed leg is voluntarily kicked backward in practice, the knee-jerk time of the percussed leg is increased relative to that of the opposite leg during practice and 10 to 20 following test blows.

(b) If the contralateral leg is kicked forward voluntarily in practice, the knee-jerk time of the contralateral leg is decreased relative to that of the percussed leg during 10 to 20 blows following.

(c) If the percussed leg is kicked forward in practice, there is little if any effect on the knee-jerk.

2. The voluntary reaction time of the contralateral leg is shorter, when the stimulus is a blow of knee-jerk strength, than to a tactual stimulus over the tendon, or to a tactual stimulus elsewhere. So also is the reaction time of the leg to a sub-KJ blow on that leg less than that to a tactual stimulus elsewhere.

3. After practice in contralateral kicking, or in back kicking of the percussed leg, the corresponding response to an unexpected tendon blow of knee-jerk strength may occasionally occur involuntarily. The degree of habituation of this response is greater in persons who are interested or who believe learning is expected.

4. Volúntary forward kicking of the contralateral leg to a knee-jerk stimulus tends to depress or abolish the knee-jerk in the percussed leg.

5. The frequency distribution of knee-jerk reaction times is bimodal in subjects exhibiting a lively knee-jerk. The bimodality is increased when a contralateral voluntary kick is made to knee-jerk stimulus.

6. The increasing of the strength of the knee-jerk stimulus by increasing the speed with which the hammer strikes the tendon seems to present three ranges. (*a*) A threshold range, within which the knee-jerk may or may not be elicited, (*b*) a second range, within which the several strengths have approximately equal effects and (*c*) a third range, in which the knee-jerk time is appreciably shortened, as compared with the second range.

These conclusions are tentative, the exploratory nature of the investigations, with necessary scattering of the data, not permitting final conclusions. The precise points on which further data need to be gathered are, however, made clear. It is obvious that the knee-jerk, in the normal individual, is no simple segmental 'reflex', but an integrated response, of a complex nature.

REFERENCES

The articles listed below include only those from which material has been used. For more complete bibliographies cf. references 15, 51 and 42.

(1) Böhme, A.: Klinische wichtige Reflexe. 1927, *Handb. d. Norm. u. Path. Physiol.*, 10: 972–1017.

(2) Brown, L. T.: The influence of exercise on muscle tonus as exhibited by the knee-jerk. 1925, *Amer. J. Physiol.*, 72: 241–247.

(3) Brown, T. G.: The intrinsic factors in the act of progression in the mammal. 1911, *Roy. Soc. Proc.*, B84: 308–319.

(4) Cason, H.: The conditioned eyelid reaction. 1922, *J. Exper. Psychol.*, 5: 153–196.

(5) Castex: Recherches sur le temps perdu du réflexe rotulien. 1905, *Rev. Neurol.*, 13: 853–854.

(6) Castex, E.: Contribution à l'étude graphique du réflexe rotulien chez l'homme. 1931, *J. Physiol. et Path. Gén.*, 29: 242–255.

(7) Creed, R. S.; Denny-Brown, D.; Eccles, J. C.; Liddell, E. G. T.; and Sherrington, C. S.: *Reflex activity of the spinal cord.* 1932, Oxford, Clarendon Press.

(8) Denny-Brown, D.: On inhibition as a reflex accompaniment of the tendon jerk and of other forms of active muscular response. 1928, *Roy. Soc. Proc.*, 103: 321–336.

(9) Dodge, R.: A systematic exploration of a normal knee-jerk. 1911, *Zeitschr. f. allg. Physiol.*, 12: 1–58.

(10) Dodge, R.: Problems of human variability. 1924, *Science*, 59: 263–270.

(11) Dodge, R.: *Elementary conditions of human variability.* 1927, New York, Col. Univ. Press.

(12) Dunlap, K.: *Habits, their making and unmaking.* 1932, New York, Liveright, Inc. Ch. II, pp. 18–42.

(13) Emery, F. E.: The influence of mental activity on the height of the knee-jerk. 1931, *Amer. J. Physiol.*, 97: 658–661.

(14) Fearing, F.: A critique of the experimental studies of inhibition with special reference to the knee-jerk. 1927, *J. Comp. Psychol.*, 7: 285–296.

(15) Fearing, F.: *Reflex action.* 1930, Baltimore, Williams & Wilkins. Ch. XV, pp. 254–277.

(16) Fulton, J. F.: *Muscular contraction and the reflex control of movement.* 1926, Baltimore, Williams & Wilkins. Pp. 644.

(17) Fulton, J. F., and Pi-Suñer, J.: A note concerning the probable function of various afferent end-organs in skeletal muscle. 1928, *Amer. J. Physiol.*, 83: 554–562.

(18) Gibson, J. J., and Hudson, L.: Bilateral transfer of the conditioned knee-jerk. 1935, *J. Exper. Psychol.*, 18: 774–783.

(19) Golla, F., and Hettwer, J.: The influence of various conditions on the time relations of tendon reflexes in the human subject. 1922, *Roy. Soc. Proc.*, B94: 92–98.

(20) Gotch, F.: Note on the so-called tendon reflex. 1896, *J. Physiol.*, 20: 322–333.

(21) HINSDALE, G., AND TAYLOR, M.: 1895, *Internat. Med. Mag.*, 4: 369.
(22) HOFFMANN, P.: Beiträge zur Kenntnis der menschlichen Reflexe mit besonderer Berücksichtigung der elektrischen Erscheinungen. 1910, *Arch f. Anat. u. Physiol., Physiol. Abth.*, 223–246.
(23) HOFFMANN, P.: Ueber die Beziehungen der Sehnenreflexe zur willkürlichen Bewegung und zum Tonus. 1918, *Zeitschr. f. Biol.*, 68: 351–370.
(24) HOFFMANN, P.: Ueber der relative Unermüdbarkeit der Sehnenreflexe. 1919, *Zeitschr. f. Biol.*, 69: 517–528.
(25) HOFFMANN, P.: *Untersuchungen über die Eigenreflexe (Sehnenreflexe) menschlicher Muskeln.* 1922, Berlin, Julius Springer. Pp. 106.
(26) HUDGINS, C. V.: Conditioning and the voluntary control of the pupillary light reflex. 1933, *J. Gener. Psychol.*, 8: 3–51.
(27) JACOBSON, E.: *Progressive relaxation.* 1929, Chicago, Univ. of Chicago Press. Pp. 429.
(28) JACOBSON, E., AND CARLSON, A. J.: The influence of relaxation upon the knee-jerk. 1925, *Amer. J. Physiol.*, 73: 324–328.
(29) KARGER, P.: Reflex, Welle und Vorstellung. 1924, *Klin. Wochenschr.*, Jr. 3 Bd. 2: 2273–2276.
(30) KING, JESSIE L.: Possible periodic variatons in the extent of the knee-jerk in women. 1918, *Amer. J. Physiol.*, 47: 404–409.
(31) KLARFELD, B.: Ergographische Untersuchungen über den Kniesehnenreflex. 1908, *Pflüg. Arch. f. d. ges. Physiol.*, 121: 404–410.
(32) LEE, MARY A. M., AND KLEITMAN, N.: Studies on the physiology of sleep. II. Attempt to demonstrate functional changes in the nervous system during experimental insomnia. 1923, *Amer. J. Physiol.*, 67: 141–152.
(33) LOMBARD, W. P.: The variations of the normal knee-jerk and their relation to the activities of the central nervous system. 1888, *Amer. J. Psychol.*, 1: 5–71.
(34) MINKOWSKI, M.: Ueber Bewegung und Reflex des menschlichen Foetus während der ersten Hälfte seiner Entwicklung. 1921, *Schweig. Arch. f. Neurol. u. Psychiat.*, 8: 148–151.
(35) MITCHELL, S. W., AND LEWIS, M. J.: Physiological studies of the knee-jerk and of the reactions of muscles under mechanical and other excitants. 1886, *Phila. Med. News*, 48: 169–173, 198–203.
(36) NYSTROM, C. L.: A comparative study of the Achilles and the patellar reflex response latencies as measured by the action-current and the muscle-thickening methods. 1933; *Univ. Iowa Stud. Psychol.*, #16; *Psychol. Monog.*, 14: #2, 61–82.
(37) PEAK, HELEN: Modification of the lid-reflex by voluntarily induced sets. 1931, *Psychol. Monog.*, 42: #1. Whole #188. Pp. 68.
(38) PEAK, HELEN: An evaluation of the concepts of reflex and voluntary action. 1933, *Psychol. Rev.*, 40: 71–89.
(39) PFAFFMAN, C., AND SCHLOSBERG, H.: The conditioned knee-jerk in psychotic and normal individuals. 1936, *J. Psychol.*, 1: 201–208.
(40) PIÉRON, H.: On the "factors influencing the latent time of the patellar reflex." 1935, *J. Exper. Psychol.*, 18: 155–157.
(41) ROSENHEIM, T.: Experimentelle Untersuchung der unter den Namen "Sehnenphänomene" bekannten Erscheinungen unter möglichster

Berücksichtigung von Versuchen an Menschen und pathologischen Beobachtungen. 1884, *Arch. f. Psychiat. u. Nervenkrankh.*, 15: 184–201.

(42) Russell, J. S. R.: The crossed knee-jerk. 1896, *Amer. J. Med. Sci.*, N. S. 11: 306–313.

(43) Schlosberg, H.: A study of the conditioned patellar reflex. 1928, *J. Exper. Psychol.*, 11: 468–494.

(44) Schwartz, A.: Zur Lehre der Haut- und Sehnenreflexe. 1882, *Arch. f. Psychiat. u. Nervenkrankh.*, 13: 621–657.

(45) Sherrington, C. S.: *The integrative action of the nervous system.* 1906, New Haven, Yale Univ. Press. Pp. 411.

(46) Sherrington, C. S.: Remarks on the reflex mechanism of the step. 1910, *Brain*, 33: 1–25.

(47) Sherrington, C. S.: Reciprocal innervation and symmetrical muscles. 1913, *Roy. Soc. Proc.*, B86: 219–232.

(48) Sherrington C. S., and Liddell, E. G. T.: Reflexes in response to stretch (myotatic reflexes). 1924, *Roy. Soc. Proc.*, B96: 212–242.

(49) Souques, A., and Chauvet, S.: Inversion des réflexes tricipitaux, réflexe contralateral du quadriceps chez un ancien hémiplégique, peut-être tabétique. 1912, *Rev. Neurol.*, 23: 717–718.

(50) Steckle, L. C., and Renshaw, E.: An investigation of the conditioned iridic reflex. 1934, *J. Gener. Psychol.*, 11: 3–23.

(51) Sternberg, M.: *Die Sehnenreflexe und ihre Bedeutung für die Pathologie des Nervensystems.* 1893, Leipzig u. Wien, Deuticke. Pp. 331.

(52) Strughold, H.: Beiträge zur Kenntnis der Refraktärphasen des menschlichen Rückenmarkes. 1927, *Zeitschr. f. Biol.*, 85: 453–469.

(53) Switzer, St. C.: Backward conditioning of the lid reflex. 1930, *J. Exper. Psychol.*, 13: 76–97.

(54) Travis, L. E., and Young, C. W.: The relation of the electromyographically measured reflex times in the patellar and Achilles reflexes to certain physical measurements and to intelligence. 1930, *J. Gener. Psychol.*, 3: 374–400.

(55) Tuttle, W. W.: The distribution of tone in skeletal muscle. 1925, *J. Exper. Psychol.*, 8: 319–322.

(56) Varnum, W.: Factors influencing the latent time of the patellar reflex. 1934, *J. Exper. Psychol.*, 17: 556–573.

(57) Walshe, F. M. R.: The physiological significance of the reflex phenomena in spastic paralysis of the lower limbs. 1914, *Brain*, 37: 369–436.

(58) Walton, G. L., and Paul, W. E.: The cerebral element in reflexes and its relation to the spinal element. 1906, *J. of Nerv. and Ment. Dis.*, 33: 681–691.

(59) de Watteville, A.: On reflexes and pseudoreflexes. 1882, *Brit. Med. J.*, 1: 736–737.

(60) Weiler, K.: Untersuchung des Kniesehnenreflexes beim Menschen. 1910, *Zeitschr. f. d. ges. Neurol. u. Psychiat.*, 1: 116–170.

(61) Wendt, G. R.: An analytical study of the conditioned knee-jerk. 1930, *Arch. Psychol.*, #123. Pp. 97.

(62) Wiersma, E. D.: Die psychologische Auffassung einiger Reflexe. 1921, *Zeitschr. f. d. ges. Neurol. u. Psychiat.*, 72: 254–266.

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